RADTRAD:
A Simplified Model for
RADionuclide Transport and
Removal And Dose Estimation

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Abstract

This report documents the RADTRAD computer code developed for the U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Reactor Regulation (NRR) to estimate transport and removal of radionuclides and dose at selected receptors. The document includes a users' guide to the code, a description of the technical basis for the code, the quality assurance and code acceptance testing documentation, and a programmers' guide. The RADTRAD code can be used to estimate the containment release using either the NRC TID-14844 or NUREG-1465 source terms and assumptions, or a user-specified table. In addition, the code can account for a reduction in the quantity of radioactive material due to containment sprays, natural deposition, filters, and other natural and engineered safety features. The RADTRAD code uses a combination of tables and/or numerical models of source term reduction phenomena to determine the time-dependent dose at user-specified locations for a given accident scenario. The code system also provides the inventory, decay chain, and dose conversion factor tables needed for the dose calculation. The RADTRAD code can be used to assess occupational radiation exposures, typically in the control room; to estimate site boundary doses; and to estimate dose attenuation due to modification of a facility or accident sequence.

Contents

Acknowledgments

Introduction

The potential radiological consequences of nuclear power reactor accidents depend in part upon the amount, form, and species of the radioactive material released during the postulated accident. The RADionuclide Transport, Removal, and Dose (RADTRAD) model estimates doses at offsite locations; for example, the exclusion area boundary (EAB) or the low population zone (LPZ), and in the control room. The code has two optional source terms to describe fission product release from the reactor coolant system: those specified in "Calculation of Distance Factors for Power and Test Reactor Sites" (TID-14844) along with Regulatory Guides 1.3 and 1.4; and those specified for boiling water reactors (BWRs) and pressurized water reactors (PWRs) in "Accident Source Terms for Light Water Nuclear power Plants" (NUREG-1465). As radioactive material is transported through the containment, the user can account for sprays and natural deposition that may reduce the quantity of radioactive material. Material can flow between buildings, from buildings to the environment, or into control rooms through high-efficiency particulate air (HEPA) filters, piping, or other connectors. An accounting of the amount of radioactive material retained due to these tortuous pathways is maintained. Decay and in-growth of daughters can be calculated over time as the material is transported. The code contains over 25 model and table options to perform these tasks. It is anticipated that the code will be used to estimate attenuation of source terms as a result of modification for a facility or accident sequence.

The RADTRAD code was developed by the Accident Analysis and Consequence Assessment Department at Sandia National Laboratories (SNL) for the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Reactor Regulation (NRR), Division of Reactor Program Management.

The code documentation is divided into four parts. The first chapter is a users' guide to the RADTRAD code. It contains the information necessary to install the code, generate an input file, run the code, and examine the output. The second chapter contains the technical basis for the code. It provides the user with the underlying assumptions and the simplifications in the models developed for the code. The third chapter is the quality assurance documentation. It includes the module testing, beta testing, and acceptance testing documentation. Chapter 4 is a programmer's guide to the code. It details the logic flow, the relationships between subprograms, and the purpose of each subprogram. Since this chapter is intended to help those who may be called upon to modify the code, it also includes a code listing.
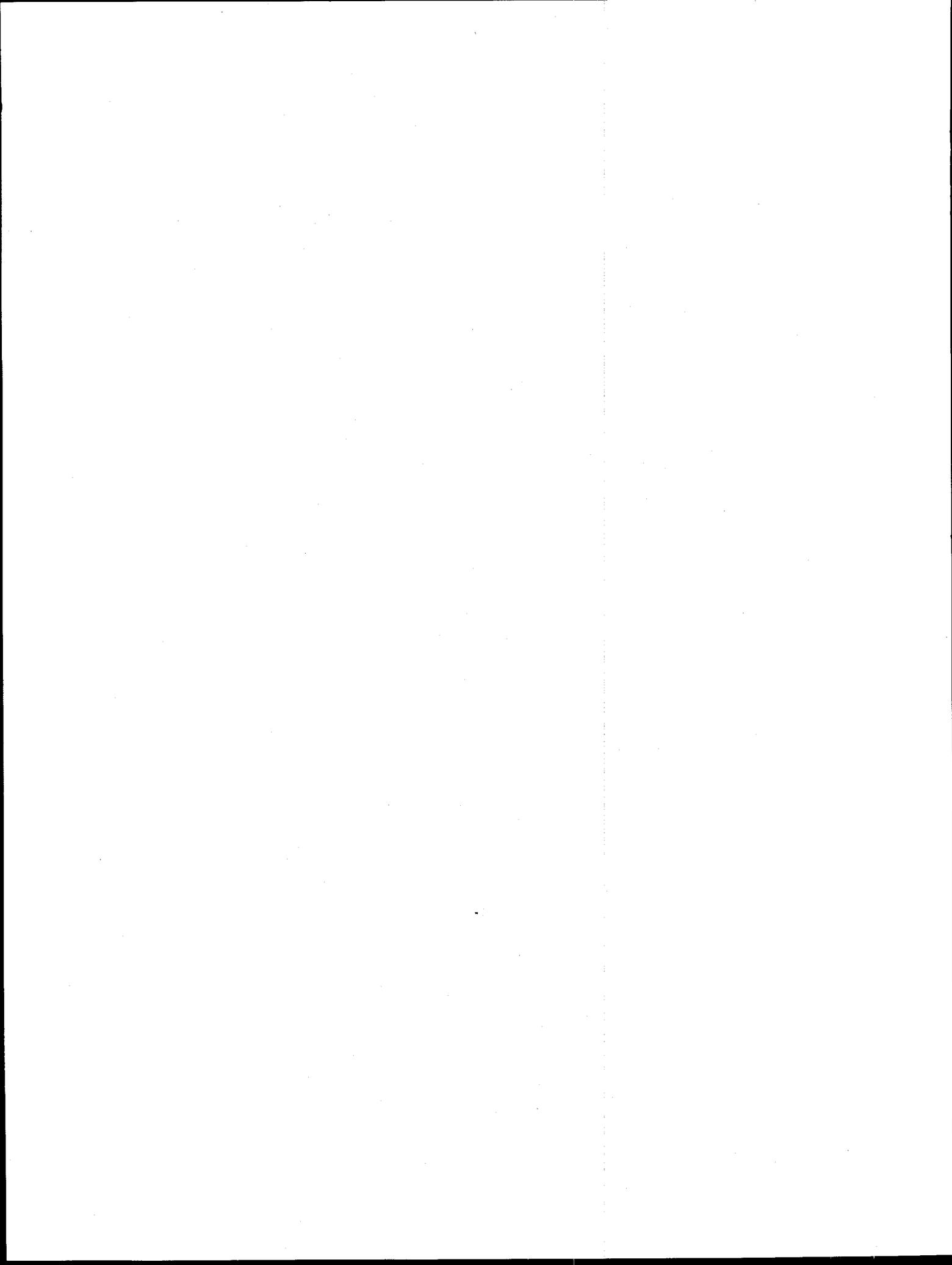
1 RADTRAD Users' Guide

This users' guide to the RADTRAD code consists of six sections. The first two sections will assist you in getting started. They describe the hardware requirements for and installation of the code. The third section describes how to run the code. It covers the user interface and data entry. The fourth section describes the input and associated files required by RADTRAD. It provides a description of each item and gives acceptable limits for the items. The fifth section shows a sample of a problem report sheet that can be used to report errors, inadequacies, or problems with the code. The sixth section contains two example problems and lists partial RADTRAD output for each problem.

1.1 Getting Started

This section of the users' guide covers the installation of the RADTRAD code on your computer. The code is supplied on a single disk. If you have the required hardware and sufficient disk space, installation of the code will be a simple matter.

1.1.1 Hardware Requirements

RADTRAD runs on personal computers using an 80386 or better processor (an IBM-compatible computer) with a math coprocessor. To ensure that the program will run correctly, the computer must have at least the following

- a high-density floppy disk drive (3.5-inch disk) and a hard disk with 3.5 megabytes of available space
- 4 megabytes of RAM
- a mouse

Running RADTRAD requires a minimum of 512 kilobytes of conventional free memory. If RADTRAD will not run, check to see if there is sufficient memory available. An error message will be displayed on the monitor. However, the message may flash by so rapidly that it isn't readable.

RADTRAD is designed to run with a mouse and thus a mouse is required. It facilitates moving through the program and selecting program options. However, RADTRAD can be run on computers without a mouse. If a mouse is not available, RADTRAD may be run by bypassing the graphical interface used for data input. An ASCII text editor can be used to create the user input files that control RADTRAD. RADTRAD may then be run by typing

```
radtrad /b   filename.pmf   filename.sdf   filename.txt
```

where *filename* plus the extensions are the plant model file, the scenario description file, and the output file. The contents and format of the specification files are described in Section 1.4.3.

1.2   Installation

RADTRAD is a DOS program and must be installed from the DOS prompt (consult your manual if you are attempting to install RADTRAD from a DOS shell or menu program). To install, exit Windows and insert the RADTRAD floppy disk into the 3.5-inch disk drive. Then follow the directions for either the default or the custom directory installation below.

1.2.1 Default Installation

Change to the disk drive on which you inserted the floppy disk. Example:

> If a: is the 3.5-inch floppy disk drive, then type:
>
> > `a:`
>
> at the command prompt and press the ENTER key.

Next, type **`install`** at the command prompt, press the enter key, and follow the instructions on the screen. This will install RADTRAD in the C:\RADTRAD directory. To run RADTRAD, change to the RADTRAD directory. Example:

> Type:
>
> > `cd c:\radtrad`
>
> at the command prompt and press the ENTER key.

Next, type **`radtrad`** at the command prompt and press the ENTER key.

1.2.2 Custom Installation

Change to the disk drive in which you inserted the floppy disk. Example:

> If a: is the 3.5-inch floppy disk drive, then type:
>
> > `a:`
>
> at the command prompt and press the ENTER key.

Next type **`install n:\your_path\your_directory`** and press the ENTER key: where **n** is your driver letter, **`your_path`** is the path name of your directory, and **`your_directory`** is the name of the directory where you want to install RADTRAD. This will install RADTRAD in the specified directory. To run RADTRAD, change to the specified directory. Example:

> Type:
>
> > `cd n:\your_path\your_directory`

at the command prompt and press the ENTER key; where *n* is your drive letter, *your_path* is the path name of your directory and *your_directory* is the name of the directory specified above.

Next type **radtrad** at the command prompt and press the ENTER key.

1.2.3 Windows Installations

Installation or execution of Windows is neither supported nor recommended. The user interface sometimes conflicts with Windows 3.1, 3.11, and Windows NT. It is completely incompatible with Windows 95. To install RADTRAD, use one of the installation procedures described above.

1.3 Running RADTRAD

RADTRAD runs under the DOS operating system. RADTRAD provides a graphical user interface for data entry, initiating execution of dose calculations, examining results, and printing output.

1.3.1 The Graphical User Interface (GUI)

RADTRAD consists of a series of screens that provide information about the code and that accept input required for the calculations. This section presents general information about interacting with the computer to run RADTRAD. Online help is available during data entry. Help is obtained by pressing the F1 key on the keyboard

1.3.2 Entering Data

In general, the instructions that follow will assume that you are using a mouse. However, the arrow keys may be used as keyboard substitutes for the mouse actions required to run the program. RADTRAD uses several methods to enter input:

- command buttons
- text boxes
- choice lists

Command buttons initiate some sort of action. To activate a command button, place the mouse cursor on the button and click with the left button on the mouse. Command buttons are labeled. The labels include **OK, CANCEL,** and **EDIT**. The **OK** button causes the code to return to the previous input screen and save the data that have been entered or modified. The **CANCEL** button causes the program to return to the previous input screen without saving any of the data that you have entered or modified. The **EDIT** button causes the program to advance to a screen where data can be input for the highlighted entry.

Text boxes are used for entering either text or numerical information. The information is entered from the keyboard. You make a text box active by clicking on the box. Information about the text box (for example, the units required and the range of appropriate values) appears at the bottom of the screen. When you move from a text box after entering data, RADTRAD will check the entry to ensure that it is proper. If an improper entry is detected, a message at the bottom of the screen will appear and you will typically be returned to the text box where the error is.

Choice lists are used to obtain information when the number of options is small. A choice list is used to specify options such as deposition mechanisms, transfer path, and compartment type. After you activate the choice list, you can move within the list using the mouse.

There is a menu bar at the top of the data input screens that lists three options -- *File, Review,* and *Help*. You use the menu bar by clicking on a listed item to can gain access to the item. The *File* option allows you to save the current input data, enter the DOS shell, or exit RADTRAD. The *Review* option allows you to examine the current input data for either the plant or scenario file. The *Help* option directs you to RADTRAD Help. If you have questions about entering specific data items, you may be able to find an answer in *Help* without leaving the program or without having to use this manual. The ESC key is used to return to the data input screens. This key can also be used during the input process to return to the previous screen. In general, with several touches of the ESC key, the user will return to the initial screen and be able to start over again or correct errors. There is a bar at the bottom of the screen that can provide additional information about the current selection.

1.3.3 Exiting RADTRAD

The method used to exit RADTRAD depends on where you are in the program. If you are at the main menu screen, you may exit the program by using the *Exit RADTRAD* selection. While you are elsewhere, you may exit the program by clicking on *Exit* in the menu bar under the *File* option. When you exit RADTRAD in any of these ways, your screen will return to its initial operating mode.

1.4 Input Description

All input to the code is through a graphical user interface (GUI). Input to the GUI may consist of selecting an option by using the mouse, entering an option number, or entering data. Data are entered in appropriate units. When the user activates a field to enter input data, the units needed automatically appear at the bottom of the GUI. On the following pages a layout is shown that indicates the relationships between screens and subscreens. A number is assigned to every screen so that during the discussion of the individual screens, the user can relate to the layout. There are currently over 60 screens and subscreens that the user could see during problem set-up. It is recommended that the user examine all subscreens related to the screens being used because defaults are limited. Note that there are a few screens that are not available. In future versions of the code they will be activated. After the screen layout, each screen is shown in a black-and-white representation of the GUI with a brief description of its use. The actual screens are colored; thus highlighting and the highlighted characters are more obvious.

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The underlying scheme of the code is that the user must first specify a nuclear power plant model and then specify a scenario description. The plant model consists of time-independent information and describes the physical structure of the plant. The user will specify the compartments, the transfer pathways that connect the compartments, and information pertaining to them (e.g., compartment volumes, the existence of filters, and suppression pools). In addition, the user will select a BWR or PWR inventory and source term. The inventory is divided into several chemical groups based on the elements in these groups with similar transport properties. The scenario description contains time-dependent information about the state of the plant and allows the user to run several different scenarios with the same plant model. The user may limit the fission products released as part of the source term. The user will be asked to select the fraction of the iodine chemical group that is elemental, organic, and aerosol. For each of the transfer pathways, the user will specify the information necessary to calculate transport and retention through that pathway (e.g., the user will specify filter efficiencies).

The user may also specify the locations of interest for calculating worker dose. Integrated air concentrations at the various locations will be determined by the code, and the user will input the exposure time, breathing rate, and other specifics needed to calculate dose equivalents.

1.4.1 Screen Numbering System

The input screens are numbered in a hierarchical manner. The more zeros there are in the screen number, the higher the decision level of the screen. Thus the main menu screen is 0000, whereas a table input deposition screen could be 2352T. The addition of a letter to the screen number denotes tabular input when it is the letter T and model input if it is a letter M. All models have an optional table input to allow the user to compare the results from using the model with results using a more familiar tabular decontamination factor.

To move from one screen to another, the user must follow the lines on the screen layout. Therefore to go from the natural deposition aerosol removal table (SN 2341T) to the spray aerosol removal table (SN 2311T), the user should go from SN 2341T (choose **OK**), to SN 2341 (choose **OK**), 2340 (choose **OK**), SN 2300A (choose *Sprays*), SN 2310 (choose *Aerosol Removal*), SN 2311 (choose *User-Specified Removal Coefficients*), and thus enter SN 2311T. This may at first be cumbersome, but because it follows the screen layout, the user soon becomes adept.

RADTRAD Screen Layout

Main Menu (0000)

Plant Model (1000)
- Load Plant Model (1100)
- Nuclide Inventory (1200)
- Select Compartment (1300)
  - Compartment Description (1310)
- Select Pathway (1400)
  - Transfer Pathway Description (1410)
    - Select Compartment (1411)
- Review Plant Model (1500)
- Save Plant Model (1600)

Scenario Description (2000)
- Load Scenario Description (2100)
- Source Term Parameters (2200)
  - Select Source Term ——— Release Fractions ——— Decay & Daughter ——— Iodine Chemical
    Compartment (2210)   and Timing (2220)   Products (2230)   Form (2240)
- Select Compartment (2300)
  - Compartment Features (2300A)

Sprays ———————	Natural ———————	Overlying ———————	Recirculating
(2310)	Deposition (2340)	Pool (2350)	Filter
			Table (2330T)
Aerosol	Aerosol	Aerosol	
Removal (2311)	Removal (2341)	Removal (2352)	
Table (2311T)	Table (2341T)	Table (2352T)	
Model (2311M)	Model (2341M)	Model (2352M)	
	Model (2341M2)		
Elemental I	Elemental I	Elemental I	
Removal	Removal	Removal	
Table (2312T)	Table (2342T)	Table (2353T)	
Organic I		Organic I	
Removal		Removal	
Table (2313T)		Table (2354T)	
		Initial Water	
		Volume (2351)	

RADTRAD Screen Layout Continued

├─ **Select Transfer Pathway (2400)**

    └─ Piping (2410) ──── Filter (2420) ──── Suppression ──────── Air
           Table (2410T)   Table (2420T)   Pool (2430)   Leakage
           Model (2410M)   X/Q (2420T2)   Table (2440T)

                                  ├─ Aerosol
                                  Removal
                                    Table (2431T)

                                  ├─ Elemental I
                                  Removal
                                    Table (2432T)

                                  └─ Organic I
                                  Removal
                                    Table (2433T)

├─ **Dose Calculation Input (2500)**

    └─ Select Dose Conversion ─ Create/Modify Dose
          Factors (2510)   Location Selection (2520)

                            └─ Create/Modify Dose
                                Locations (2520A)

                                  ├─ Location Compartment (2521)
                                  ├─ Control Room (2522)
                                  └─ Environment (2523)

├─ **Review Scenario Description (2600)**

└─ **Save Scenario Description (2700)**

Calculate Results (3000)

Examine Results (4000)

    └─ **Examine Output File (4100)**

Exit RADTRAD (5000)

1.4.2 Detailed Screen Input

This section contains all of the screens that are used for the RADTRAD user-interface. The order of the screens presented follows the order that a user would normally encounter them when inputting a new problem. The following conventions will be used when describing the screens:

Bold with Initial Caps	represents the name of a screen
Italics with Initial Caps	represents the name of a data field or non-numeric user-specified data
SMALL CAPS	represents a key on the keyboard. e.g., ESC

The convention used to number the screens is explained in Section 1.4.1.

Welcome to RADTRAD

RADionuclide Transport, Removal, And Dose code

Developed by Sandia National Laboratories
for the
Division of Reactor Program Management
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555
NRC JCN J2453

Version 2.20
December 25, 1997

Press any key or mouse button to continue.

This is the title screen and has no number associated with it. It indicates that a successful loading and initiation of the RADTRAD code has occurred. The user should note the version number and date in the lower left corner. This information allows others, such as the developers, to determine which code version the user has. Press any key or mouse button to continue.

```
┌──────────────────────────────────────────────────────────────────────────────┐
│ File  Review   Plant File = TEST24.PMF    Scenario File = TEST24.SDF    Help   │
│                                 RADTRAD                                         │
│                 RADionuclide Transport, Removal, And Dose code                  │
│                                                                                │
│                                                                                │
│                         ┌────────────────────────────┐                         │
│                         │ (1) Plant Model            │                         │
│                         └────────────────────────────┘                         │
│                                                                                │
│                         ┌────────────────────────────┐                         │
│                         │ (2) Scenario Description    │                         │
│                         └────────────────────────────┘                         │
│                                                                                │
│                         ┌────────────────────────────┐                         │
│                         │ (3) Calculate Results       │                         │
│                         └────────────────────────────┘                         │
│                                                                                │
│                         ┌────────────────────────────┐                         │
│                         │ (4) Examine Results         │                         │
│                         └────────────────────────────┘                         │
│                                                                                │
│                         ┌────────────────────────────┐                         │
│                         │ (5) Exit RADTRAD            │                         │
│         Version 2.20    └────────────────────────────┘                         │
│         December 25, 1997                                                       │
│                                                                    SN 0000      │
└──────────────────────────────────────────────────────────────────────────────┘
```

The **RADTRAD, RADionuclide Transport, Removal, And Dose code** main menu is screen
number 0000. This screen allows the user to develop the input and run RADTRAD. The user
should go through the listed options in order. Typically the user will first model the plant, then
model the scenario, and finally calculate results. A *Scenario Description* cannot be defined
without a *Plant Model* to which the scenario can be referenced. Also, a *Scenario Description* and
Plant Model must be available for a calculation to be performed. The user may examine results
from previous calculations without running the code by choosing *Examine Results* and specifying
the output file from that calculation. The user may *Exit RADTRAD* from the main menu by
choosing this option at any time.

Plant Model

(1) Load Plant Model	(4) Transfer Pathways
(2) Nuclide Inventory	(5) Review Plant Model
(3) Compartment Description	(6) Save Plant Model

(7) Return to Main Menu

SN 1000

The **Plant Model** menu is screen number. This screen allows the user to describe the time-independent plant input. The user may select a previously defined plant model for modification or create a new plant model. In most cases a previously defined model will exist; the user then clicks on the first option to retrieve the file into an active status. The user selects the *Nuclide Inventory, Compartment Description,* or *Transfer Pathways* options in order to specify or modify information about the plant model in those areas. The *Review Plant Model* option allows the user to examine the plant model input as it is currently defined. The *Save Plant Model* option allows the user to save the current plant model in a file of their choice. The name of the current plant file is shown on top of the screen. Selecting *Return to Main Menu* will return the user to screen number 0000.

```
 File  Review   Plant File = TEST24.PMF    Scenario File = TEST24.SDF    Help
                          Plant Model
                         Load Plant Model



             Enter Plant Model path and file name
            ┌──────────────────────────────────────────────┐
            │ ACCEPT\TEST24.PMF                            │
            └──────────────────────────────────────────────┘




           ┌──────────┐                  ┌──────────┐
           │    OK    │                  │  CANCEL  │
           └──────────┘                  └──────────┘             SN 1100
            The file name can be up to 40 characters long.
```

The **Load Plant Model** is screen number 1100. This screen allows the user to specify the path and file name of the input data that describe the plant model that the user wishes to modify. Clicking on **OK** or **CANCEL** will return the user to the **Plant Model** menu (screen number 1000).

Plant Model
Nuclide Inventory

Default PWR Inventory	Default BWR Inventory	Default TID Inventory	User-Specified Inventory

Select Nuclide Inventory

(∎)	( )	( )	( )

Plant Power   `0.3992E+04`

File Name   `DEFAULTS\PWR_DEF.NIF`   EDIT

OK   CANCEL

SN 1200

Select the Default PWR, BWR, TID-14844, or user inventory.

The **Nuclide Inventory** is screen 1200. This screen allows the user to select from the available options for nuclide inventories. It is invoked when the user selects *Nuclide Inventory* on the **Plant Model** menu. Currently the user may select a typical BWR, PWR or the NRC's generic Technical Information Document (TID) inventory as detailed in Section 1.4.3.3. In addition, inventory files for only ^{131}I have been supplied in the DEFAULTS subdirectory. Alternatively, the user may supply a file that contains the user-specified inventory. The user must enter the nominal thermal *Plant Power* (MWt) in the appropriate location. The ratio of the input power to inventory power is used to determine the inventory used for the plant analysis. Only one of the options can be selected (i.e., a PWR and BWR inventory cannot be specified at the same time). If the user specifies a file containing an inventory, the file format will be checked for consistency with the description in Section 1.4.3.3 and an error will result if the format is incorrect. Clicking on **OK** or **CANCEL** will return the user to the **Plant Model** menu (screen number 1000).

Plant Model
Compartment Descriptions
Select Compartment

```
 1 │ Sprayed Region
 2 │ Unsprayed Region
 3 │ Annulus
 4 │ Environment
 5 │ Control Room
 6 │ Unused
 7 │ Unused
 8 │ Unused
 9 │ Unused
10 │ Unused
```

EDIT

OK

SN 1300

Select compartment to edit then enter return or press EDIT.

The **Select Compartment** menu is screen number 1300. It is invoked when the user selects *Compartment Description* from the **Plant Model** menu. To add a compartment, the user highlights the first available *Unused* entry and clicks on **EDIT**. This will bring up a subscreen that allows data to be input. Upon returning from the subscreen, the new compartment name entered will have replaced the *Unused* entry and the next *Unused* entry will be highlighted. This continues until the user has defined all the compartments. A maximum of 10 compartments are allowed in a plant model. The more compartments that there are, the slower the code executes. The speed of execution increases more than linearly for an increase in compartments, but less than the square. Clicking on **OK** will return the user to the **Plant Model** menu (screen number 1000).

```
┌──────────────────────────────────────────────────────────────────────────┐
│ File  Review   Plant File = TEST24.PMF     Scenario File = TEST24.SDF   Help│
│                          Plant Model                                        │
│                     Compartment Description                                 │
│                                                                             │
│    Compartment Name  ┌──────────────────────────────────────────┐          │
│                      │Sprayed Region                            │          │
│                      └──────────────────────────────────────────┘          │
│                                                                             │
│    Compartment Type  ┌────────────────────────────────────────────────┐    │
│                      │( )Unused ( )Control Room  ( )Environment (■)Other│    │
│                      └────────────────────────────────────────────────┘    │
│                                                                             │
│    Compartment Volume ┌──────────────┐                                     │
│                       │0.2740E+07    │                                     │
│                       └──────────────┘                                     │
│                                                                             │
│                      ┌─────────────────────────────────────────────────┐   │
│      Compartment     │(*)Sprays    ( )Filters (Recirculating)  ( )Overlying│
│        features      │                                          Pool    │   │
│                      │( )Sumps     ( )Natural Deposition                │   │
│                      └─────────────────────────────────────────────────┘   │
│                                                                             │
│              ┌──────────┐              ┌──────────┐                         │
│              │    OK    │              │  CANCEL  │        SN 1310          │
│              └──────────┘              └──────────┘                         │
│                    Enter or edit the compartment name.                      │
└──────────────────────────────────────────────────────────────────────────┘
```

The **Compartment Description** is screen number 1310. This screen allows the user to enter specific information for a compartment. The name of the compartment is input at the top of the page where the example shows *Sprayed Region*. This name will be used throughout the input and output as the identifier for this compartment. The user may use up to 40 characters for this identifier. The *Compartment Volume* is in units of cubic feet and must be input in scientific notation. If the compartment represents a control room or the environment, the appropriate box must be checked. *Other* represents volumes where doses will not be calculated, such as containments, auxiliary buildings, and turbine rooms. Only one control room is allowed in a calculation; hence if a user needs the dose in another room, there must be two separate calculations. If the compartment represents the environment, both the compartment volume and compartment features are removed from the screen when the user clicks on the *Environment* button, indicating that the user does not use these inputs. *Unused* is checked only when the user wants to eliminate the volume from the calculation but retain its data in the input deck. The features available in the compartment are also listed. The user must select the appropriate box(es) on this screen to activate the removal mechanism screens (screen numbers 2300-2354T) during the scenario model input. The user should choose only features that are appropriate for the volume being described. For example, an *Overlying Pool* may exist in a containment but not in a control room because it is associated with postvessel failure scenarios. Clicking on **OK** or on **CANCEL** will return the user to the **Select Compartment** menu (screen number 1300).

Plant Model
Transfer Pathways
Select Pathway

```
┌──────────────────────────────────────────────────┐
│ ░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░ │
│ ┌────────────────────────────────┐ ▲             │
│ │ Sprayed to Unsprayed           │ █   ┌───────┐ │
│ │ Sprayed to Annulus             │ ░   │ EDIT  │ │
│ │ Sprayed to Environment         │ ░   └───────┘ │
│ │ Unsprayed to Sprayed           │ ░             │
│ │ Unsprayed to Annulus           │ ░             │
│ │ Unsprayed to Environment       │ ░   ┌───────┐ │
│ │ Annulus to Environment         │ ░   │  OK   │ │
│ │ Filter 3--Environment to CR    │ ░   └───────┘ │
│ │ Unfiltered--Environment to CR  │ ░             │
│ │ Exhaust from CR to Environment │ ▼             │
│ └────────────────────────────────┘               │
│ ░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░░ │
└──────────────────────────────────────────────────┘
```

SN 1400

Select a pathway to edit, then enter return or press EDIT.
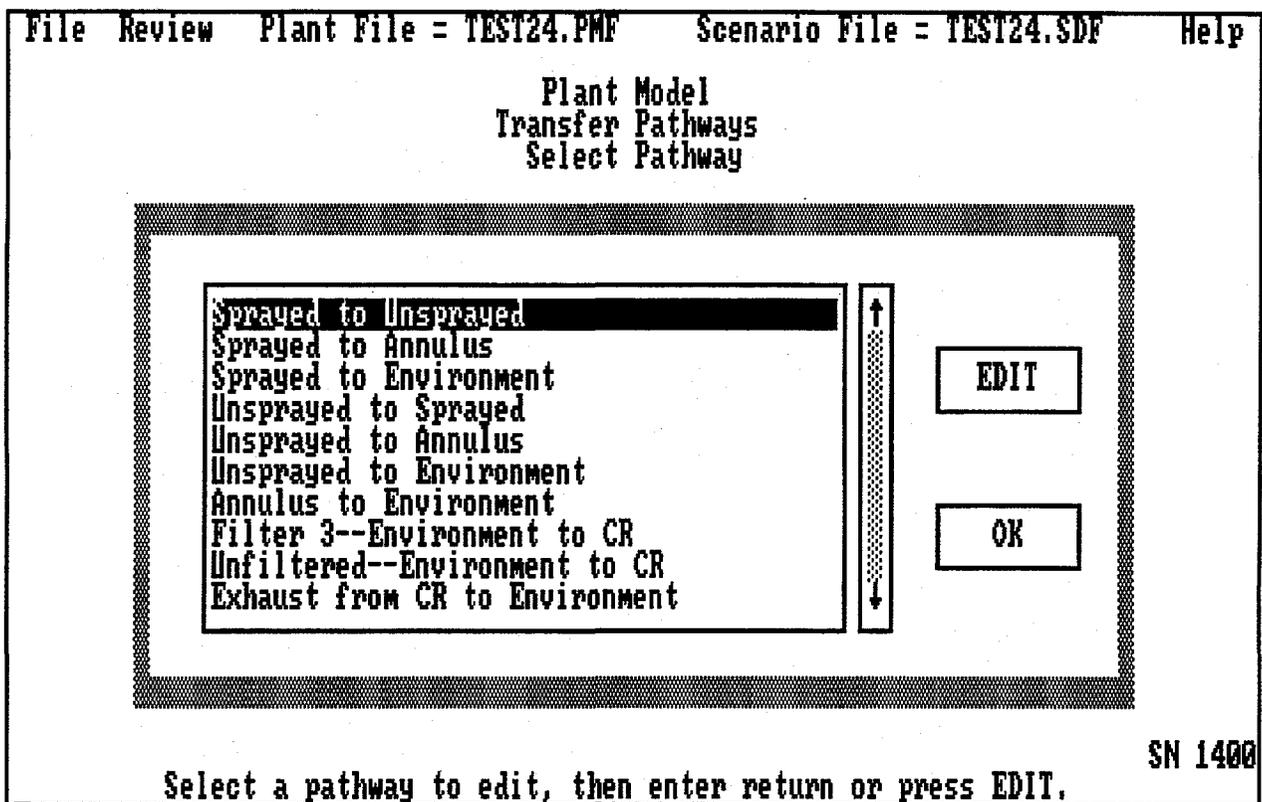
The **Select Pathway** menu is screen number 1400. This screen allows the user to identify the flow paths that connect compartments. It is invoked when the user selects *Transfer Pathways* on the **Plant Model** screen. To add a pathway, the user must specify information about each transfer pathway by selecting the first available *Unused* entry, which is then highlighted, and click on **EDIT**. This brings up a subscreen. The user continues entering transfer paths in this way until the problem is defined. The number of paths does not dramatically affect the execution time. Clicking on **OK** or on **CANCEL** will return the user to the **Plant Model** menu (screen number 1000).

Plant Model
Transfer Pathway Description

Pathway Name

Sprayed to Unsprayed

Pathway from Compartment

Sprayed Region

Pathway to Compartment

Unsprayed Region

Transfer Mechanisms

( )Unused

( )Piping

( )Filter

( )Suppression Pool

(■)Air Leakage

OK		CANCEL

SN 1410

Enter or edit the pathway name.

The **Transfer Pathway Description** is screen 1410. This screen allows the user to enter specific information for the transfer pathway selected in screen 1400. The user may have multiple paths between compartments; for example, filtered and unfiltered air from the environment to the control room. The name of the transfer pathway is input at the top of the screen where the example shows *Sprayed to Unsprayed*. A double click on the *Pathway from Compartment* will activate a list of compartment names on screen 1411. The user highlights one and returns, thus identifying the "from" compartment. This method ensures correct linkage with earlier data. The *Pathway to Compartment* is then double clicked and entered. The user must click on an appropriate transfer mechanism for the pathway to be able to activate the transfer mechanism screens (screen numbers 2400-2440T) during the scenario description (only one is allowed for each pathway). The choice of a pathway *Transfer Mechanism* is a function of the data available to the user. For example, the leakage option allows for no filtration, but a variation in flow versus time, while filters allow for variation in filtration versus time at constant flow. In addition, the filter option can access the environment as its *Pathway from Compartment*. Both the *Piping* and *Suppression Pool* options allow for a variation of both filtration and flow versus time. In addition, the *Piping* option has a model to calculate deposition as a function of geometry, flow, and the pressure and temperature. *Unused* allows the user to remove a transfer path from the calculation but retain it in the input deck. It is recommended that the user be familiar with the acceptance tests detailed in Section 3.3 to specify transfer path mechanisms appropriate for the problem. For example, *Air Leakage* has been used for containment leaks and *Filters* for unfiltered in-flow into the control room. Clicking on **OK** or on **CANCEL** will return the user to the **Select Pathway** screen (screen number 1400).

Plant Model
Transfer Pathway Compartment
Select Compartment

1	Sprayed Region
2	Unsprayed Region
3	Annulus
4	Environment
5	Control Room
6	Unused
7	Unused
8	Unused
9	Unused
10	Unused

OK

CANCEL

SN 1411

Click on name to edit name - double click to edit parameters.
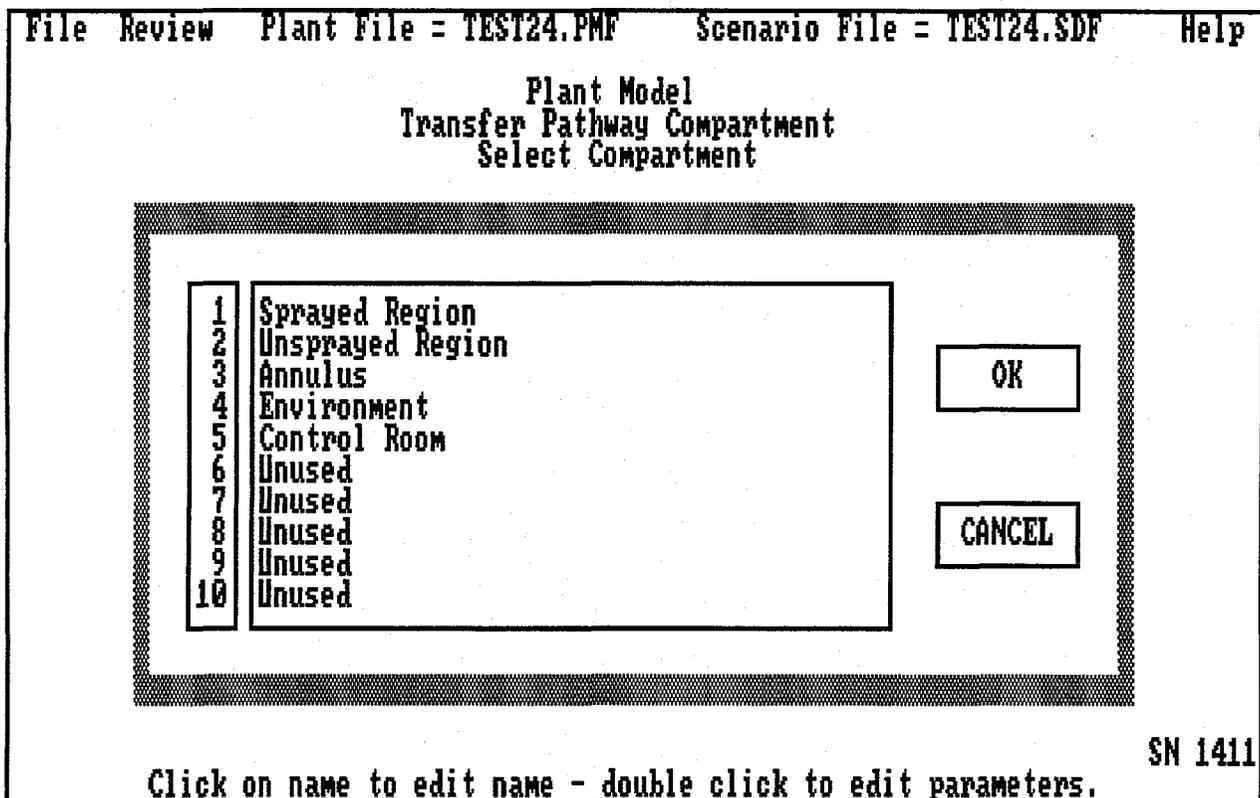
The **Select Compartment** menu is screen number 1411. This screen allows the user to select the compartments at the beginning and end of a transfer pathway. The user highlights the desired compartment and clicks **OK** to return to the transfer pathway screen and correctly input the connection volume. Clicking on **OK** or **CANCEL** will return the user to the **Transfer Pathway Description** screen (screen number 1410).

Review Plant Model -- Press the ESC key to exit.   SN 1500

```
############################################################################
                 RADTRAD Version 2.20  12/20/97 12:58:36.54
############################################################################


############################################################################
                           File information
############################################################################

Plant file name          = ACCEPT\TEST24.PMF
Inventory file name       = DEFAULTS\PWR_DEF.NIF
Scenario file name        = ACCEPT\TEST24.SDF
Release file name         = DEFAULTS\PWR_DBA.RFT
Dose conversion file name = DEFAULTS\FGR60.INP


############################################################################
                          Plant Description
############################################################################

Number of Nuclides =    0
```

The **Review Plant Model** is screen number 1500. This screen allows the user to review the input used to define the current plant model by using the scroll bar on the right-hand side of the screen. Return to the **Plant Model** menu (screen number 1000) by using the escape key (ESC) on the keyboard.

```
                             Plant Model
                           Save Plant Model




             Enter Plant Model path and file name
            ┌─────────────────────────────────────────────┐
            │ ACCEPT\TEST24.PMF                           │
            └─────────────────────────────────────────────┘




            ┌──────────────┐              ┌──────────────┐
            │      OK      │              │    CANCEL    │
            └──────────────┘              └──────────────┘
                                                              SN 1600
            The file name can be up to 40 characters in length.
```

The **Save Plant Model** is screen number 1600. This screen allows the user to specify a file name for saving the plant model. It is invoked when the user selects *Save Plant Model* on screen 1000. Note the convention of XXX.PMF where XXX is the user description and PMF stands for plant model file. Typical files names may include subdirectories such as *ACCEPT\TEST10.PMF* or simply *PERRYMAN.PMF*. Clicking on **OK** or **CANCEL** will return the user to the **Plant Model** menu (screen number 1000). The user should be aware that the PMF files available with the code are read only and that trying to save changes using the original file name will result in a system error.

Scenario Description

```
┌──────────────────────────────────┐      ┌──────────────────────────────────┐
│ (1) Load Scenario Description     │      │ (5) Dose Parameters              │
└──────────────────────────────────┘      └──────────────────────────────────┘

┌──────────────────────────────────┐      ┌──────────────────────────────────┐
│ (2) Source Term Parameters        │      │ (6) Review Scenario Description  │
└──────────────────────────────────┘      └──────────────────────────────────┘

┌──────────────────────────────────┐      ┌──────────────────────────────────┐
│ (3) Compartment Features          │      │ (7) Save Scenario Description    │
└──────────────────────────────────┘      └──────────────────────────────────┘

┌──────────────────────────────────┐      ┌──────────────────────────────────┐
│ (4) Transfer Pathways             │      │ (8) Return to Main Menu          │
└──────────────────────────────────┘      └──────────────────────────────────┘
```

SN 2000

The **Scenario Description** menu is screen number 2000. It allows the user to input the time-dependent aspects of the problem. It is invoked when the user selects *Scenario Description* on screen 1000. The user *must* have a plant model file (XXX.PMF) active before starting this file. The user may select a previously defined scenario description or may create a new one. From this screen the user may choose to develop time-dependent information concerning the *Source Term*, the *Compartments*, and the *Transfer Pathways*. *View Scenario Description* allows the user to examine the scenario input as it is currently defined. The user may view the status of the plant at any selected time after accident initiation. The *Save Scenario Description* option allows the user to save the current scenario in a file of his or her choice. The name of the current file is shown on the top of the screen. Selecting *Return to Main Menu* will return the user to screen number 0000.

Scenario Description
Load Scenario Description

Enter Scenario Description path and file name

```
ACCEPT\TEST24.SDF
```

| OK | | CANCEL |

SN 2100

The file name can be up to 40 characters long.

The **Load Scenario Description** is screen number 2100. This screen allows the user to specify the path and file name of the input data that contain the scenario description the user wishes to modify. Clicking on **OK** or **CANCEL** will return the user to the **Scenario Description** menu (screen number 2000).

```
                         Scenario Description
                        Source Term Parameters



              ┌─────────────────────────────────────┐
              │ (1) Source Term Compartment          │
              └─────────────────────────────────────┘

              ┌─────────────────────────────────────┐
              │ (2) Release Fractions and Timing     │
              └─────────────────────────────────────┘

              ┌─────────────────────────────────────┐
              │ (3) Decay & Daughter Products        │
              └─────────────────────────────────────┘

              ┌─────────────────────────────────────┐
              │ (4) Iodine Chemical Form             │
              └─────────────────────────────────────┘

              ┌─────────────────────────────────────┐
              │ (5) Return to Scenario Description    │
              └─────────────────────────────────────┘


                                               SN 2200
```

The **Source Term Parameters** menu is screen number 2200. This screen allows the user to enter subscreens and provide information on the source term. It is invoked when the user selects *Source Term* on screen 1000. The user must go through each subscreen if this is a new scenario, because defaults are limited. The user inputs the *Compartment* to which radioactive materials are released, the *Release Fractions and Timing*, the possibility of *Decay & Daughter Products* and the *Chemical Form* of the released iodine. Selecting *Return to Scenario Description* will return the user to screen number 2000.

Source Term Parameters
Select Source Term Compartment

1	Sprayed Region
2	Unsprayed Region
3	Annulus
4	Environment
5	Control Room
6	Unused
7	Unused
8	Unused
9	Unused
10	Unused

OK

CANCEL

SN 2210

Click on name to edit name - double click to select.

The **Select Source Term Compartment** menu is screen number 2210. This screen allows the user to specify the compartment in which the source term is released by selecting a compartment from the list in the plant model. Clicking on **OK** or **CANCEL** will return the user to the **Source Term Parameters** menu (screen number 2200).

```
┌─────────────────────────────────────────────────────────────────────────┐
│ File  Review   Plant File = TEST24.PMF    Scenario File = TEST24.SDF  Help│
│ ┌───────────────────────────────────────────────────────────────────────┐│
│ │                        Scenario Description                            ││
│ │                       Source Term Parameters                           ││
│ │                    Release Fractions and Timing                        ││
│ │                                                                        ││
│ │              PWR    BWR                                                 ││
│ │            ┌──────────────┐                                            ││
│ │ Reactor Type│ (■)    ( ) │                                            ││
│ │            └──────────────┘                                            ││
│ │               TID        1465/DBA      1465/SA         Other           ││
│ │            ┌──────────────────────────────────────────────────────┐   ││
│ │ Release Type│  ( )          (■)          ( )            ( )       │   ││
│ │            └──────────────────────────────────────────────────────┘   ││
│ │            ┌──────────┐                                                ││
│ │ Delay Time │ 0.0000  │                                                ││
│ │            └──────────┘                                                ││
│ │            ┌───────────────────────────────────────┐   ┌──────┐       ││
│ │ File Name  │DEFAULTS\PWR_DBA.RFT                    │   │ EDIT │       ││
│ │            └───────────────────────────────────────┘   └──────┘       ││
│ │            ┌──────────┐                    ┌──────────┐                ││
│ │            │   OK    │                    │ CANCEL  │                 ││
│ │            └──────────┘                    └──────────┘     SN 2220    ││
│ │   Note: this selector is ignored for release types 'TID' and 'Other'. ││
│ └───────────────────────────────────────────────────────────────────────┘│
└─────────────────────────────────────────────────────────────────────────┘
```

The **Release Fractions and Timing** screen is screen number 2220. This screen allows the user to select PWR, BWR, TID, or default values for the fractions, timing, and amount of nonradioactive aerosol released. This screen is invoked when the user selects *Release Fractions and Timings* on screen 2200. The selection for release fractions should be consistent with what was chosen on screen number 1200 for the plant nuclide inventory. The code has files for the TID, design basis, and severe accident release patterns which are described in Section 1.4.3.1. These should be used for most scenarios. If the user chooses to modify the release fractions or timings, this is the screen where it can be done. The user may also modify the time between shutdown and the start of release on this screen by using the *Delay Time* field. This allows the inventory to decay before its release. Clicking on **OK** or **CANCEL** will return the user to the **Source Term Parameters** menu (screen number 2200).

Scenario Description
Source Term Parameters
Decay & Daughter Products

No Decay No Daughter Products	Decay No Daughter Products	Decay Daughter Products
(■)	( )	( )

```
┌──────┐                    ┌────────┐
│  OK  │                    │ CANCEL │
└──────┘                    └────────┘
                                          SN 2230
```

Select the desired option.

The **Decay & Daughter Products** menu is screen number 2230. It is invoked by selecting *Decay & Daughter Products* on screen number 2200. This screen allows the user to specify whether fission product decay will be included and whether daughter products will also be included in the calculation. Daughter in-growth is not possible without decay. Section 2.4.3 discusses the theory used in these models. Clicking on **OK** or **CANCEL** will return the user to the **Source Term Parameters** menu (screen number 2200).

```
                        Scenario Description
                        Source Term Parameters
                          Iodine Chemical Form




                          Elemental      Organic       Aerosol

        Iodine Chemical Fractions  [0.0485]     [0.0015]      [0.9500]







              [   OK   ]                    [CANCEL]
                                                              SN 2240
        The initial fraction of elemental iodine in the source term.
```

The **Iodine Chemical Form** menu is screen number 2240. This screen allows the user to specify the chemical form of the iodine as it is released into the compartment chosen in screen number 2210. This screen is invoked when the user specifies *Iodine Chemical Form* on screen 2200. The fractional amounts of each form must sum to 1.0 or an error message will result. The TID release assumes an iodine form that is ~91% elemental while NUREG/1465 assumes that the iodine is 95% aerosol. The user should be consistent. Removal processes affect the chemical form differently. Typically, aerosols are the easiest to remove and organics the most difficult. This screen has been used for revolatilization studies in which the organic release is higher at the end than it is at the beginning. For that case, acceptance test 13, the end-state fractions, were used here and an organic iodine deposition rate versus time was used to get the proper release pattern. Clicking on **OK** or **CANCEL** will return the user to the **Source Term Parameters** menu (screen number 2200).

Scenario Description
Compartment Features
Select Compartment

1	Sprayed Region
2	Unsprayed Region
3	Annulus
4	Environment
5	Control Room
6	Unused
7	Unused
8	Unused
9	Unused
10	Unused

EDIT

OK

SN 2300

Select compartment to edit, then enter return or press EDIT.
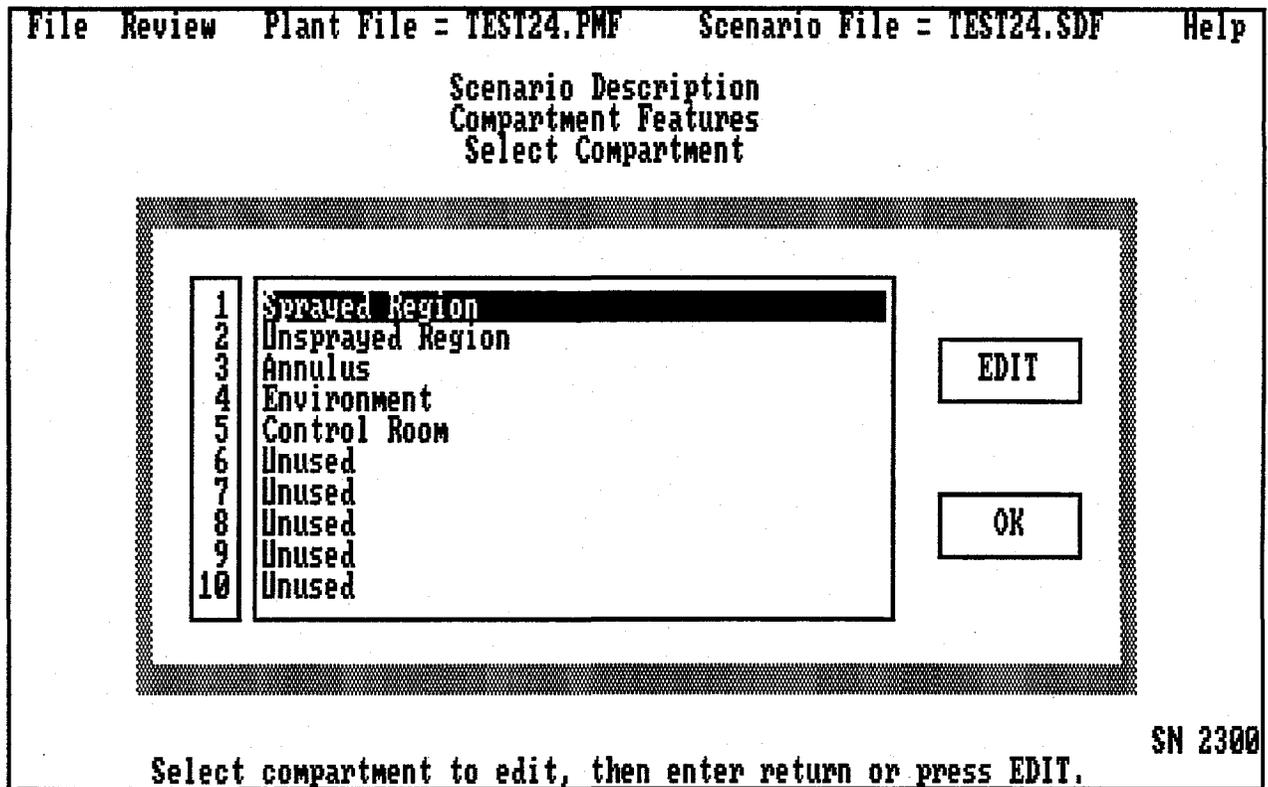
The **Select Compartment** menu of the scenario file is screen number 2300. It is invoked when the user selects *Compartments* on the **Scenario Description** screen. The compartment names are taken from the current plant file. The user must specify information about each compartment by highlighting that compartment and clicking on the **EDIT** button. If the user clicks on **OK**, the user is returned to the **Scenario Description** menu (screen number 2000).

```
 File  Review   Plant File = TEST24.PMF    Scenario File = TEST24.SDF    Help

                Scenario Description: Compartment Features
                            Sprayed Region

Selected Removal Mechanisms      Edit Removal Mechanisms        Compartment
                                                                Detailed
  ┌──────────────────────┐      ┌───────────────────────┐       Output
  │ Sprays          (*)  │      │ (1) Sprays            │       Requested
  │                      │      └───────────────────────┘      ┌──────────────┐
  │ Sumps           ( )  │      ┌───────────────────────┐      │ Yes( ) No(■) │
  │                      │      │ (2) Sumps             │      └──────────────┘
  │ Filters         ( )  │      └───────────────────────┘
  │                      │      ┌───────────────────────┐
  │ Natural Deposition ( )│     │ (3) Filters (recirculating) │
  │                      │      └───────────────────────┘
  │ Overlying Pool  ( )  │      ┌───────────────────────┐
  └──────────────────────┘      │ (4) Natural Deposition │
                                └───────────────────────┘
                                ┌───────────────────────┐
                                │ (5) Overlying Pool    │
                                └───────────────────────┘

            ┌────────┐                      ┌────────┐
            │   OK   │                      │ CANCEL │
            └────────┘                      └────────┘                SN 2300A
        Select if detailed output for a given compartment is desired.
```

The **Compartment Features** menu is screen number 2300A. This screen allows the user to input data about a compartment's features and to enhance the output concerning the compartment. The compartment name is listed at the top of the screen. The user can specify information about the individual compartment features by selecting them only if there is an X in the box to the left of the option. The X will appear if the option had been chosen in the plant model input of screen 1310. If the user wants to add a feature, he or she must first go back to screen 1310, mark it there, return to this screen, and click on the feature button. If the user desires detailed output regarding the results from the features in this compartment, the box under *Compartment Detailed Output Requested* must be checked. Detailed output includes the isotopic mass distributions for this volume as well as the group deposition on all surfaces and in all pathways connected to this volume. An example of this output is given in Section 1.5. Clicking on **OK** will return the user to the **Select Compartment** screen (screen number 2300).

Scenario Description
Compartment Features: Sprays

Sprayed Region

Selected Models   Edit Model Parameters

| Aerosol   (*) |
| Elemental Iodine (*) |
| Organic Iodine   (*) |

(1) Aerosol Removal

(2) Elemental Iodine Removal

(3) Organic Iodine Removal

(4) Return to Compartment Features Menu

SN 2310

The **Sprays** menu is screen number 2310. This screen allows the user to include information for spray removal of fission products if the spray feature was chosen in screen 1310 and clicked on in screen 2300A. The user may specify information on *Aerosol Removal, Elemental Iodine Removal,* and/or *Organic Iodine Removal* by selecting these options. All fission products removed by sprays are placed in the sump of the compartment indicated at the top of the screen. Selecting *Return to Compartment Features Menu* will return the user to screen number 2300A.

```
┌─────────────────────────────────────────────────────────────────────┐
│ File  Review   Plant File = TEST24.PMF    Scenario File = TEST24.SDF   Help │
│                        Scenario Description                          │
│                   Compartment Features: Sprays                      │
│                        Aerosol Removal                              │
│                                                                     │
│                        Sprayed Region                               │
│                                                                     │
│                                                                     │
│          Select Model                  Edit Model Parameters        │
│       ┌────────────────────┐  ┌──────────────────────────────────┐ │
│       │ User-Specified ( ) │  │ (1) User-Specified Removal Coefficients │
│       │                    │  └──────────────────────────────────┘ │
│       │                    │                                        │
│       │ Powers        (■)  │  ┌──────────────────────────────────┐ │
│       │                    │  │ (2) Powers Model for Removal Coefficients │
│       │                    │  └──────────────────────────────────┘ │
│       │ None          ( )  │  ┌──────────────────────────────────┐ │
│       └────────────────────┘  │ (3) Return to Sprays Menu        │ │
│                               └──────────────────────────────────┘ │
│                                                                     │
│                                                          SN 2311    │
└─────────────────────────────────────────────────────────────────────┘
```

The **Aerosol Removal by Sprays** menu is screen number 2311. This screen allows the user to choose either the *User-Specified Removal Coefficients* as a function of time or the *Powers Model*. This screen is entered by selecting *Aerosol Removal* on screen 2310. The user may specify only one of these methods for providing the code with removal coefficients. If both are specified, an error message will result and the user will have to clear one of the subscreens. Selecting *Return to Sprays Menu* returns the user to screen number 2310.

Scenario Description
Compartment Features: Sprays
Aerosol Removal: User-Specified Removal Coefficients

Sprayed Region

Time	Removal Coefficient
0.0000	0.0000
0.0000	0.0000
0.0000	0.0000
0.0000	0.0000
0.0000	0.0000

OK   CANCEL

SN 2311T

Time (hr).

The **User-Specified Removal Coefficients** for aerosols are screen number 2311T. This screen allows the user to specify the time dependence of the aerosol removal coefficient. When the sprays are not operating, the user should specify a removal coefficient of 0.0. The *Removal Coefficient* will change in a stepwise fashion at each *Time* that it is defined to change. Acceptance test case 23 details typical values for a PWR; the units are fraction removed of the total aerosol mass inserted into the containment per second. Clicking on **OK** or **CANCEL** will return the user to the **Aerosol Removal by Sprays** menu (screen number 2311).

Scenario Description
Compartment Features: Sprays
Aerosol Removal: Powers Model for Removal Coefficients

Sprayed Region

Time	Flux	Height
0.0000	0.0394000	85.0000
3.0000	0.0000000	85.0000
0.0000	0.0000000	0.0000
0.0000	0.0000000	0.0000
0.0000	0.0000000	0.0000

Fraction Sprayed `1.0000`   Percentile `( )10%  (■)50%  ( )90%`

`OK`   `CANCEL`

SN 2311M

Time (hr).

The **Powers Model for Removal Coefficients** for aerosols is screen number 2311M. This screen allows the user to specify the parameters necessary to calculate the aerosol removal by sprays using a model developed by Powers and Burson [Po93] as a function of time. The *Flux* is in units of volumetric flow of spray per area of coverage, typically taken as the containment volume over its height (ft^3/min-ft^2). The *Height* of sprays above the floor is in feet. The range of values used during the development of the model was from 0.3 to 80 ft^3/s-ft^2 of spray water *Flux* and from 16 to 160 ft full height. The values will change in a stepwise fashion at each *Time* that they are defined to change. The user may also specify which *Percentile* of the model should be used in the calculation. Ten percent represents the lower bound, 50% represents the median or best estimate, and 90% represents an upper bound that results in the largest decontamination factor. The user may also specify the *Fraction* of sprayed volume to total compartment volume. The theory used in developing this model is given in Section 2.1. Note that acceptance test case 24 used this option and separated sprayed and unsprayed zones due to the high removal ratio chosen. Clicking on **OK** or **CANCEL** will return the user to the **Aerosol Removal by Sprays** menu (screen number 2311).

```
┌─────────────────────────────────────────────────────────────────────────┐
│ File  Review   Plant File = TEST24.PMF    Scenario File = TEST24.SDF  Help │
│                                                                           │
│                          Scenario Description                             │
│                       Compartment Features: Sprays                        │
│             Elemental Iodine Removal: User-Specified Removal Coefficients  │
│                                                                           │
│                              Sprayed Region                               │
│                                                                           │
│                                                                           │
│                     Time       Removal Coefficient                        │
│                   ┌─────────┐    ┌─────────┐                              │
│                   │ 0.0000  │    │  1.5000 │                              │
│                   │ 0.5000  │    │ 12.0000 │                              │
│                   │ 1.8000  │    │  5.0000 │                              │
│                   │ 2.0000  │    │  2.0000 │                              │
│                   │ 8.0000  │    │  0.4000 │                              │
│                   └─────────┘    └─────────┘                              │
│                                                                           │
│            Select User Coefficients  │Yes(■)  No( )│                      │
│                                                                           │
│                                                                           │
│           ┌──────────┐                      ┌──────────┐                 │
│           │    OK    │                      │  CANCEL  │                 │
│           └──────────┘                      └──────────┘     SN 2312T     │
│                              Time (hr).                                    │
└─────────────────────────────────────────────────────────────────────────┘
```

The **User-Specified Removal Coefficients** for elemental iodine are obtained in screen number 2312T. This screen allows the user to specify the time dependence of the elemental iodine removal coefficient (hr^{-1}). When the sprays are not operating, then the user should specify a removal coefficient of 0.0. In acceptance test cases 23 and 24, the elemental iodine removal coefficient had the same value as the aerosol removal coefficient for case 23. The *Removal Coefficient* will change in a stepwise fashion at each *Time* that it is defined to change. The user must have the *Select User Coefficients* button on *Yes* for the code to use the tabular input. When it is set to *No*, then the removal coefficient is always 0.0. Clicking on **OK** or **CANCEL** will return the user to the **Sprays** menu (screen 2310).

Scenario Description
Compartment Features: Sprays
Organic Iodine Removal: User-Specified Removal Coefficients

Sprayed Region

Time	Removal Coefficient
0.0000	0.0000
0.0000	0.0000
0.0000	0.0000
0.0000	0.0000
0.0000	0.0000

Select User Coefficients   Yes(■) No( )

OK   CANCEL

SN 2313T

Time (hr).

The **User-Specified Removal Coefficients** for organic iodine are screen number 2313T. This screen allows the user to specify the time dependence of the organic iodine removal coefficient. When the sprays are not operating, then the user should specify a removal coefficient of 0.0. The *Removal Coefficient* will change in a stepwise fashion at each *Time* that it is defined to change. Organics are generally not affected by sprays; hence organic iodine removal coefficients of 0.0 are reasonable. The user must have the *Select User Coefficients* button on *Yes* for the code to use the tabular input. When it is set to *No*, the removal coefficient is always 0.0. Clicking on **OK** or **CANCEL** will return the user to the **Sprays** menu (screen number 2310).

```
┌─────────────────────────────────────────────────────────────────────┐
│ File  Review   Plant File = TEST24.PMF    Scenario File = TEST24.SDF   Help │
│                                                                       │
│                          Scenario Description                         │
│              Compartment Features: Filters (recirculating)            │
│                     User-Specified Filter Parameters                  │
│                                                                       │
│                             Control Room                              │
│                                                                       │
│                      Aerosol      Elemental I    Organic I            │
│            Time     Efficiency    Efficiency     Efficiency           │
│         ┌──────────┐ ┌──────────┐ ┌──────────┐ ┌──────────┐           │
│         │   0.0000 │ │  99.0000 │ │  95.0000 │ │  95.0000 │           │
│         │ 720.0000 │ │  99.0000 │ │  95.0000 │ │  95.0000 │           │
│         │   0.0000 │ │   0.0000 │ │   0.0000 │ │   0.0000 │           │
│         │   0.0000 │ │   0.0000 │ │   0.0000 │ │   0.0000 │           │
│         │   0.0000 │ │   0.0000 │ │   0.0000 │ │   0.0000 │           │
│         └──────────┘ └──────────┘ └──────────┘ └──────────┘           │
│                                                                       │
│   Forced Flow Rate │0.4000E+04│   Select User Parameters │Yes(■) No( )│ │
│                                                                       │
│           ┌──────────┐                    ┌──────────┐                │
│           │    OK    │                    │  CANCEL  │                │
│           └──────────┘                    └──────────┘     SN 2330T   │
│                             Time (hr).                                 │
└─────────────────────────────────────────────────────────────────────┘
```

The **User-Specified Filter Parameters** are screen number 2330T. The screen is reached by initializing *Filters (Recirculating)* on screen 1310 and then clicking on *Filters (Recirculating)* on screen 2300A. This screen allows the user to enter information about the effectiveness of a recirculating air filter within a compartment, such as a control room, as a function of time. The capture efficiencies are input separately for the *Aerosol*, *Elemental I*, and *Organic I* groups. It is assumed that the noble gas group cannot be captured. The efficiencies will change in a stepwise fashion at each *Time* that they are defined to change. The constant *Forced Volumetric Flow Rate* is also input. If the user requires a variable flow rate, then the user-defined pipe feature is recommended. The user must have the *Select User Parameters* button on *Yes* for the code to use the tabular input. When it is set to *No,* then the efficiencies are all 0.0. Recirculating filters were used extensively in the acceptance test problems; typical values can be found in Section 3.3. Clicking on **OK** or **CANCEL** will return the user to the **Compartment Features** menu (2300A).

```
┌─────────────────────────────────────────────────────────────────────┐
│ File  Review   Plant File = TEST24.PMF    Scenario File = TEST24.SDF  Help │
│                                                                       │
│                         Scenario Description                          │
│              Compartment Features: Natural Deposition                 │
│                                                                       │
│                         Unsprayed Region                              │
│                                                                       │
│                                                                       │
│        Selected  Models                  Edit Model Parameters        │
│     ┌───────────────────────┐   ┌───────────────────────────────────┐ │
│     │ Aerosol        (*)    │   │ (1)  Aerosol  Removal             │ │
│     │                       │   └───────────────────────────────────┘ │
│     │                       │                                         │
│     │ Elemental Iodine ( )  │   ┌───────────────────────────────────┐ │
│     └───────────────────────┘   │ (2)  Elemental Iodine Removal     │ │
│                                 └───────────────────────────────────┘ │
│                                                                       │
│                                 ┌───────────────────────────────────┐ │
│                                 │ (3)  Return to Compartment Features Menu │
│                                 └───────────────────────────────────┘ │
│                                                                       │
│                                                        SN 2340        │
└─────────────────────────────────────────────────────────────────────┘
```

The **Natural Deposition** menu is screen number 2340. This screen is reached by initializing the *Natural Deposition* button on screen 1310 and by double clicking on the *Natural Deposition* pad on screen 2300A This screen allows the user to include information on natural deposition. The user may specify information on *Aerosol* or *Elemental Iodine Removal* by selecting these options and double clicking. Selecting *Return to Compartment Features Menu* returns the user to screen number 2300A.

```
┌─────────────────────────────────────────────────────────────────────┐
│ File  Review   Plant File = TEST24.PMF     Scenario File = TEST24.SDF    Help │
│                                                                         │
│                        Scenario Description                             │
│              Compartment Features: Natural Deposition                   │
│                         Aerosol Removal                                 │
│                                                                         │
│                         Unsprayed Region                                │
│                                                                         │
│        Select Model                      Edit Model Parameters          │
│   ┌──────────────────────┐  ┌──────────────────────────────────────┐  │
│   │ User-Specified (■)   │  │ (1) User-Specified Removal Coefficients │ │
│   │                      │  └──────────────────────────────────────┘  │
│   │                      │  ┌──────────────────────────────────────┐  │
│   │ Henry        ( )     │  │ (2) Henry Aerosol Deposition Model      │ │
│   │                      │  └──────────────────────────────────────┘  │
│   │                      │  ┌──────────────────────────────────────┐  │
│   │ Powers       ( )     │  │ (3) Powers Aerosol Deposition Containment Model │ │
│   │                      │  └──────────────────────────────────────┘  │
│   │                      │  ┌──────────────────────────────────────┐  │
│   │ None         ( )     │  │ (4) Return to Natural Deposition Menu   │ │
│   └──────────────────────┘  └──────────────────────────────────────┘  │
│                                                                         │
│                                                          SN 2341        │
└─────────────────────────────────────────────────────────────────────┘
```

The **Aerosol Removal by Natural Deposition** menu is screen number 2341. This screen allows the user to choose the aerosol *Removal Coefficients* as a function of time or implement one of the two models for natural deposition of aerosols. Only one of the options may be active. If information is specified for more than one of the options, then the last model selected is used. Selecting *Return to Natural Deposition Menu* returns the user to screen number 2340.

Scenario Description
Compartment Features: Natural Deposition
Aerosol Removal: User-Specified Removal Coefficients

Unsprayed Region

Time	Removal Coefficient
0.0000	0.1500
720.0000	0.1500
0.0000	0.0000
0.0000	0.0000
0.0000	0.0000

| OK | | CANCEL |

SN 2341T

Time (hr).

The **User-Specified Removal Coefficients** for aerosols are screen number 2341T. This screen allows the user to specify the removal coefficient (hr^{-1}) as a function of time for the natural deposition of aerosols. The *Removal Coefficient* will change in a stepwise fashion at each *Time* it is defined to change. Acceptance test cases 4, 9, 22, 23 and 24 used this option with a value of 0.15/hr or 4.167×10^{-5}/s for input. Clicking on **OK** or **CANCEL** will return the user to the **Aerosol Removal by Natural Deposition** menu (screen number 2341).

Scenario Description
Compartment Features: Natural Deposition
Aerosol Removal: Henry Aerosol Deposition Model

Unsprayed Region

Time	Fall Height	Particle Density
0.0000	0.0000E+00	0.0000E+00
720.0000	0.0000E+00	0.0000E+00
0.0000	0.0000E+00	0.0000E+00
0.0000	0.0000E+00	0.0000E+00
0.0000	0.0000E+00	0.0000E+00

OK   CANCEL

Time (hr).

SN 2341M

The **Henry Aerosol Deposition Model** for aerosol removal [Fa84] is screen number 2341M. This screen allows the user to provide input for the Henry correlation for natural deposition as described in Section 2.2.1.1.1. The deposition *Fall Height* (ft) and *Particle Density* (g/cm^3) will change in a stepwise fashion at each time it is defined to change. Acceptance test cases 5 and 10A exercised this option using a fall height of 16.4 ft and the density of water (1 g/cm^3) for the particle density. In many situations the aerosols are not at their theoretical density due to the way they were formed. If the user knows the effective density, it should be used. The range of applicability of this simple model is not well defined. Clicking on **OK** or **CANCEL** will return the user to the **Aerosol Removal by Natural Deposition** menu (screen number 2341).

```
                          Scenario Description
                 Compartment Features: Natural Deposition
            Aerosol Removal: Powers Aerosol Deposition Containment Model

                             Unsprayed Region


  Reactor & Accident Type    ┌──────────────────────────────────────────┐
                             │ ( ) PWR - Design Basis Accident            │
  Note: this model applies   │ ( ) PWR - Severe Accident                  │
  only to containment        │                                            │
  compartments.              │ ( ) BWR - Design Basis Accident            │
                             │ ( ) BWR - Severe Accident                  │
                             │                                            │
                             │ ( ) APWR - Design Basis Accident           │
                             └──────────────────────────────────────────┘

                             ┌──────────────────────────────────────────┐
           Percentile        │ (■) 10%        ( ) 50%        ( ) 90%      │
                             └──────────────────────────────────────────┘


          ┌──────────────┐                    ┌──────────────┐
          │      OK       │                    │    CANCEL     │
          └──────────────┘                    └──────────────┘              SN 2341M2
                    Select the reactor and accident type.
```

The **Powers Aerosol Deposition Containment Model** for aerosol removal [Po95], is screen number 2341M2. This screen allows the user to provide input for the Powers model for natural deposition of aerosols. This model is reasonable only for a large building and, according to the author, is not valid for deposition in passages such as pipes. The model is described in Section 2.2.1.1.2. The user should be consistent in the choice of reactor and accident types with the release fractions chosen on screen 2220. The user must specify an uncertainty percentile; 10% represents the lower bound, 50% the best estimate or median, and 90% the upper bound or largest removal coefficient. Acceptance test case 10 exercised this option. It was a PWR design and looked at the best estimate solution for a design basis accident. Clicking on **OK** or **CANCEL** will return the user to the **Aerosol Removal by Natural Deposition** menu (screen number 2341).

```
 File  Review   Plant File = TEST24.PMF     Scenario File = TEST24.SDF     Help

                           Scenario Description
                   Compartment Features: Natural Deposition
             Elemental Iodine Removal: User-Specified Removal Coefficients

                               Unsprayed Region


                      Time      Removal Coefficients
                      ┌──────────┐   ┌──────────┐
                      │ 0.0000   │   │ 0.0000   │
                      │ 0.0000   │   │ 0.0000   │
                      │ 0.0000   │   │ 0.0000   │
                      │ 0.0000   │   │ 0.0000   │
                      │ 0.0000   │   │ 0.0000   │
                      └──────────┘   └──────────┘

               Select User Coefficients  │Yes( )  No(■)│


                 ┌──────────┐              ┌──────────┐
                 │    OK    │              │  CANCEL  │
                 └──────────┘              └──────────┘
                                                          SN 2342T
                           Time (hr).
```

The **User-Specified Removal Coefficients** for elemental iodine are screen number 2342T. This screen allows the user to specify the removal coefficient as a function of time for the natural deposition of elemental iodine. The *Removal Coefficient* will change in a stepwise fashion at each *Time* it is defined to change. Acceptance test cases 4, 5, 9, 10, 23 and 24 all exercised this option by using the above table; however, there was no elemental *Iodine Removal Coefficient* input. The user must have the *Select User Coefficients* button on *Yes* for the code to use the tabular input. When it is set to *No* the removal coefficient is always 0.0. Clicking on **OK** or **CANCEL** will return the user to the **Natural Deposition** menu (screen number 2340).

```
┌──────────────────────────────────────────────────────────────────────────┐
│ File  Review   Plant File = TEST24.PMF    Scenario File = TEST24.SDF  Help │
│                         Scenario Description                               │
│               Compartment Features: Overlying Pool                         │
│                                                                            │
│                           Sprayed Region                                   │
│                                                                            │
│                                  Edit Model Parameters                     │
│                          ┌──────────────────────────────────────────┐      │
│                          │ (1) Initial Overlying Pool Water Volume   │      │
│        Selected Models   └──────────────────────────────────────────┘      │
│        ┌──────────────┐  ┌──────────────────────────────────────────┐      │
│        │ Aerosol   ( )│  │ (2) Aerosol Decontamination Factors       │      │
│        │              │  └──────────────────────────────────────────┘      │
│        │              │  ┌──────────────────────────────────────────┐      │
│        │ Elemental Iodine ( )│ (3) Elemental Iodine Decontamination Factors │
│        │              │  └──────────────────────────────────────────┘      │
│        │ Organic Iodine ( )│ ┌────────────────────────────────────────┐    │
│        └──────────────┘  │ (4) Organic Iodine Decontamination Factors │    │
│                          └──────────────────────────────────────────┘      │
│                          ┌──────────────────────────────────────────┐      │
│                          │ (5) Return to Compartment Features Menu   │      │
│                          └──────────────────────────────────────────┘      │
│                                                           SN 2350           │
└──────────────────────────────────────────────────────────────────────────┘
```

The **Overlying Pool** is described in screen number 2350. This screen is entered by initializing the *Overlying Pool* option on screen 1310 and then choosing the *Overlying Pool* pad on screen 2300A. This screen allows the user to reduce the source term due to an overlying pool that may be available after the vessel fails and part of the core falls to the containment floor. The user must input *an Initial Overlying Pool Water Volume* and may choose any or all of the decontamination methods. The default is a decontamination factor of 1.0, or no decontamination of any group. This option is typically used after vessel failure when the partially ejected core and the releasing fission products are covered with water. It has not been assessed because it deals only with severe accident space. Selecting *Return to Compartment Features Menu* returns the user to screen number 2300A.

Scenario Description
Compartment Features: Overlying Pool
Initial Water Volume

Sprayed Region

Initial Water Volume

```
0.0000E+00
```

```
   OK              CANCEL
```

Initial overlying pool volume (ft^3).

SN 2351

The **Overlying Pool Initial Water Volume** is screen number 2351. This screen allows the user to input the *Initial Water Volume* (ft^3) overlying the molten core. Clicking on **OK** or **CANCEL** will return the user to the **Overlying Pool** menu (screen number 2350).

```
┌─────────────────────────────────────────────────────────────────────────┐
│ File  Review   Plant File = TEST24.PMF    Scenario File = TEST24.SDF  Help │
│                                                                           │
│                          Scenario Description                             │
│                   Compartment Features: Overlying Pool                    │
│                           Aerosol Removal                                 │
│                                                                           │
│                             Sprayed Region                                │
│                                                                           │
│         Select Model                      Edit Model Parameters           │
│     ┌─────────────────────┐  ┌──────────────────────────────────────────┐│
│     │ User-Specified ( )  │  │ (1) User-Specified Aerosol Decontamination Factors ││
│     │                     │  └──────────────────────────────────────────┘│
│     │                     │                                               │
│     │                     │  ┌──────────────────────────────────────────┐│
│     │ Powers         ( )  │  │ (2) Powers Aerosol Decontamination Factors Model ││
│     │                     │  └──────────────────────────────────────────┘│
│     │                     │                                               │
│     │                     │  ┌──────────────────────────────────────────┐│
│     │ None           (■)  │  │ (3) Return to Overlying Pool Menu        ││
│     └─────────────────────┘  └──────────────────────────────────────────┘│
│                                                                           │
│                                                              SN 2352      │
│                  Select the model you wish to use or none.                │
└─────────────────────────────────────────────────────────────────────────┘
```

The **Overlying Pool Aerosol Removal** menu is screen number 2352. This screen allows the user to choose between a user-specified time-dependent decontamination factor and the Powers model [PO92] for aerosol decontamination factor in overlying pools. Only one of these methods may be used. Selecting *Return to Overlying Pool Menu* will return the user to screen number 2350.

```
 File  Review   Plant File = TEST24.PMF    Scenario File = TEST24.SDF    Help

                         Scenario Description
                  Compartment Features: Overlying Pool
         Aerosol Removal: User-Specified Aerosol Decontamination Factors

                           Sprayed Region


                    Time      Decontamination Factor

                   ┌─────────┐        ┌─────────┐
                   │ 0.0000  │        │ 0.0000  │
                   │ 0.0000  │        │ 0.0000  │
                   │ 0.0000  │        │ 0.0000  │
                   │ 0.0000  │        │ 0.0000  │
                   │ 0.0000  │        │ 0.0000  │
                   └─────────┘        └─────────┘


            ┌──────────┐              ┌──────────┐
            │    OK    │              │  CANCEL  │
            └──────────┘              └──────────┘
                                                        SN 2352T
                        Time (hr).
```

The **User-Specified Aerosol Decontamination Factors** for aerosol removal due to an overlying pool are screen number 2352T. This screen allows the user to specify the aerosol decontamination factor for the overlying pool as a function of time from accident initiation. The *Decontamination Factor* will change in a stepwise fashion at each *Time* that it is defined to change. The decontamination factor must be ≥1.0. Clicking on **OK** or **CANCEL** will return the user to **Overlying Pool Aerosol Removal** menu (screen number 2352).

```
┌──────────────────────────────────────────────────────────────────────┐
│ File  Review   Plant File = TEST24.PMF   Scenario File = TEST24.SDF  Help │
│                                                                        │
│                       Scenario Description                             │
│                 Compartment Features: Overlying Pool                    │
│         Aerosol Removal: Powers Aerosol Decontamination Factor Model    │
│                                                                        │
│                          Sprayed Region                                │
│                                                                        │
│           Time          Pool Depth    Pool Temperature                 │
│        ┌──────────┐   ┌──────────────┐  ┌──────────────┐              │
│        │ 0.0000   │   │ 0.0000E+00   │  │ 212.0000     │              │
│        │ 0.0000   │   │ 0.0000E+00   │  │ 212.0000     │              │
│        │ 0.0000   │   │ 0.0000E+00   │  │ 212.0000     │              │
│        │ 0.0000   │   │ 0.0000E+00   │  │ 212.0000     │              │
│        │ 0.0000   │   │ 0.0000E+00   │  │ 212.0000     │              │
│        └──────────┘   └──────────────┘  └──────────────┘              │
│                                                                        │
│        Percentile  ┌──────────────────────────────────┐               │
│                    │ (■) 10%     ( ) 50%    ( ) 90%    │               │
│                    └──────────────────────────────────┘               │
│                                                                        │
│        ┌──────────┐                    ┌──────────┐                    │
│        │    OK    │                    │  CANCEL  │                    │
│        └──────────┘                    └──────────┘    SN 2352M        │
│                        Time (hr).                                      │
└──────────────────────────────────────────────────────────────────────┘
```

The **Powers Aerosol Decontamination Factor Model** for aerosol removal is screen number
2352M. This screen allows the user to specify the *Pool Depth* (ft) and degree of subcooling (°F)
as a function of time. The derived model, as described in Section 2.2.3.1, only examined pool
depths between 1 and 6 ft; it also examined subcooling between 0 and 126°F (if the compartment
pressure is 1 atm, this corresponds to water temperatures between 86 and 212°F). Its use outside
these ranges is not recommended. The pool height and pool subcooling will change in a stepwise
fashion at each time that they are defined to change. The lower bound is associated with the 10%
option, the best estimate with the 50% option, and the upper bound with the 90% option.
Clicking on **OK** or **CANCEL** will return the user to the **Overlying Pool Aerosol Removal**
menu (screen number 2352).

```
File  Review   Plant File = TEST24.PMF      Scenario File = TEST24.SDF      Help

                           Scenario Description
                    Compartment Features: Overlying Pool
            Elemental Iodine Removal: User-Specified Decontamination Factors

                              Sprayed Region


                  Time     Decontamination Factor

                        ┌─────────┐   ┌─────────┐
                        │ 0.0000  │   │ 0.0000  │
                        │ 0.0000  │   │ 0.0000  │
                        │ 0.0000  │   │ 0.0000  │
                        │ 0.0000  │   │ 0.0000  │
                        │ 0.0000  │   │ 0.0000  │
                        └─────────┘   └─────────┘


        Select User Decontamination Factors  │Yes( )  No(■)│


              ┌──────────┐              ┌──────────┐
              │    OK    │              │  CANCEL  │
              └──────────┘              └──────────┘
                                                        SN 2353T
                          Time (hr).
```

The **User-Specified Decontamination Factors** for elemental iodine removal are screen number
2353T. This screen allows the user to specify the elemental iodine decontamination factor for
the overlying pool as a function of time. *Decontamination factors* for elemental iodine would
probably be large for the range of pool sizes allowed by the aerosol decontamination model. The
Decontamination Factor will change in a stepwise fashion at each *Time* that it is defined to
change. The user must have the *Select User Decontamination Factors* button on *Yes* for the code
to use the tabular input. When it is set to *No*, the decontamination factor is always 1.0. Clicking
on **OK** or **CANCEL** will return the user to the **Overlying Pool** menu (screen number 2350).

Scenario Description
Compartment Features: Overlying Pool
Organic Iodine Removal: User-Specified Decontamination Factors

Sprayed Region

Time	Decontamination Factor
0.0000	0.0000
0.0000	0.0000
0.0000	0.0000
0.0000	0.0000
0.0000	0.0000

Select User Decontamination Factors   Yes( )   No(■)

OK		CANCEL

SN 2354T

Time (hr).

The **User-Specified Decontamination Factors** for organic iodine removal are screen number 2354T. This screen allows the user to specify the organic iodine decontamination factor for the overlying pool as a function of time. Decontamination factors for organic iodine would probably be small for the range of pool sizes allowed by the aerosol decontamination model. The *Decontamination Factor* will change in a stepwise fashion at each *Time* that it is defined to change. The user must have the *Select User Decontamination Factors* button on *Yes* for the code to use the tabular input. When it is set to *No*, the decontamination factor is always 1.0. Clicking on **OK** or **CANCEL** will return the user to the **Overlying Pool** menu (screen number 2350).

Scenario Description
Transfer Pathways
Select Transfer Pathway

```
┌──────────────────────────────────┐  ↑
│ Sprayed to Unsprayed             │  ▓
│ Sprayed to Annulus               │  ▓
│ Sprayed to Environment           │  ▓        ┌─────────┐
│ Unsprayed to Sprayed             │  ▓        │  EDIT   │
│ Unsprayed to Annulus             │  ▓        └─────────┘
│ Unsprayed to Environment         │  ▓
│ Annulus to Environment           │  ▓
│ Filter 3--Environment to CR      │  ▓        ┌─────────┐
│ Unfiltered--Environment to CR    │  ▓        │   OK    │
│ Exhaust from CR to Environment   │  ▓        └─────────┘
└──────────────────────────────────┘  ↓
```

SN 2400

Select a pathway to edit, then enter return or press EDIT.

The **Select Transfer Pathway** menu of the scenario files is screen 2400. This screen allows the user access to the time-dependent transfer pathway input. It is invoked when the user selects *Transfer Pathways* on the **Scenario Description** menu. All transfer pathway names for the plant model under consideration are listed. The information appears in a scroll box. The user may specify scenario-dependent information on subscreens for any of the pathways by highlighting that pathway and selecting **EDIT**. The user must have initialized the model on screen 1411. For example, activation of the piping option input depends upon this earlier selection. If the user has selected either no option or an incorrect option, he or she should return to screen 1411 and correct the problem. Clicking on **OK** will return the user to the **Scenario Description** menu (screen 2000).

```
┌─────────────────────────────────────────────────────────────────────┐
│ File  Review   Plant File = TEST24.PMF    Scenario File = TEST24.SDF   Help │
│                         Scenario Description                          │
│                      Transfer Pathways: Piping                       │
│                                                                       │
│                       Annulus to Environment                          │
│                                                                       │
│                                                                       │
│         Select Model                    Edit Model Parameters         │
│      ┌──────────────────┐      ┌──────────────────────────────────┐  │
│      │ User-Specified (■)│      │ (1)  User-Specified Removal Coefficients │ │
│      │                  │      └──────────────────────────────────┘  │
│      │                  │                                             │
│      │                  │      ┌──────────────────────────────────┐  │
│      │ Brockmann    ( ) │      │ (2)  Brockmann Model             │  │
│      │                  │      └──────────────────────────────────┘  │
│      │                  │                                             │
│      │                  │      ┌──────────────────────────────────┐  │
│      │ None         ( ) │      │ (3)  Return to Transfer Pathways Menu │ │
│      └──────────────────┘      └──────────────────────────────────┘  │
│                                                                       │
│                                                           SN 2410     │
└─────────────────────────────────────────────────────────────────────┘
```

The **Transfer Pathways: Piping** is screen number 2410. This screen allows the user to include information on fission product removal in the piping. The selection chosen will be used to determine the deposition of aerosols, elemental iodine, and organic iodine in a pipe. The user may elect to input user-specified decontamination factors and volumetric flow rates as a function of time from accident initiation or may select a model. The user may only specify one of these methods for providing the code with decontamination factors. Selecting *Return to Transfer Pathways Menu* returns the user to **Select Transfer Pathway** (screen number 2400).

Scenario Description
Transfer Pathways: Piping
User-Specified Removal Coefficients

Annulus to Environment

Time	Flow Rate	Aerosol DF	Elemental Iodine DF	Organic Iodine DF
0.0000	0.0000E+00	100.0000	1.0000	1.0000
0.0278	0.1400E+05	100.0000	1.0000	1.0000
0.2778	0.1000E+04	100.0000	1.0000	1.0000
0.0000	0.0000E+00	0.0000	0.0000	0.0000
0.0000	0.0000E+00	0.0000	0.0000	0.0000

```
[ OK ]            [ CANCEL ]
```

Time (hr).

SN 2410T

The **User-Specified Removal Coefficients** are screen number 2410T. This screen allows the user to specify the time dependence of the aerosol, elemental iodine, and organic iodine decontamination factors and the volumetric flow rate through the pipe. The values for *Flow Rate* (cfm), *Aerosol, Elemental Iodine, and Organic Iodine Decontamination Factors* are changed in a stepwise fashion at each *Time* that they are defined to change. Decontamination factors are always ≥1.0. This option was exercised in acceptance test cases 13 and 13B. In these cases, a detailed analysis using the Cline model was carried out at Pacific Northwest National Laboratory and the effective efficiencies necessary to duplicate the results were input in terms of decontamination factors. In that model all the aerosols and elementals as well as a varying part of the organics were deposited in the pipe. Clicking on **OK** or **CANCEL** will return the user to the **Transfer Pathways: Piping** menu (screen number 2410).

Scenario Description
Transfer Pathways: Piping
Brockmann Model

Annulus to Environment

Time	Flow Rate	Gas Pressure	Gas Temperature
0.0000	0.0000E+00	0.0000E+00	0.0000E+00
0.0000	0.0000E+00	0.0000E+00	0.0000E+00
0.0000	0.0000E+00	0.0000E+00	0.0000E+00
0.0000	0.0000E+00	0.0000E+00	0.0000E+00
0.0000	0.0000E+00	0.0000E+00	0.0000E+00

Volume 0.0000E+00   Inner Surface Area 0.0000E+00   Total Pipe Bend Angle 0.0000E+00

OK   CANCEL

SN 2410M

Time (hr).

The **Brockmann Model** is screen number 2410M. This screen allows the user to enter data for the Brockmann–Bixler [Br91, Bi95] models described in Section 2.2.6. The model needs the total surface area (ft^2), volume (ft^3), and bend angle (degree) in the pipe to determine the geometric relationships. It then uses the *Gas Pressure* and *Flow Rate* variations to determine aerosol deposition. The tabular properties are changed in a stepwise fashion at each *Time* (hr) that they are defined to change. Although the models used in the Brockmann model are very general, the experimental base is not perfect. The pressure (cfm), temperature (F) and flow (cfm) limits are not defined, but tens of atmospheres, thousands of degrees, or sonic flow are well beyond the model's capabilities, as are supersaturated conditions. The combination of *Volume* and *Inner Surface Area* is used to determine the effective diameter, which is then used to determine the length. The *Total Pipe Bend Angle* is the sum in degrees of all the angles that the flow moves through. Thus one 90° and two 45° are summed as one 180°, and the value 180 is input. Clicking **OK** or **CANCEL** will return the user to the **Transfer Pathways: Piping** menu (screen number 2410).

Scenario Description
Transfer Pathway: Filter
User-Specified Filter Parameters

Filter 3--Environment to CR

Flow Rate	Time	Aerosol Efficiency	Elemental I Efficiency	Organic I Efficiency
0.2000E+04	0.0000	99.0000	95.0000	95.0000
	720.0000	99.0000	95.0000	95.0000
	0.0000	0.0000	0.0000	0.0000
Edit Intake X/Qs	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000

OK   CANCEL

SN 2420T

Time (hr).

The **User-Specified Filter Parameters** are screen number 2420T. This screen allows the user to enter information about the removal efficiency of an air filter between compartments as a function of time (hr) and flow rate (cfm). The values for aerosol and iodine efficiencies are changed in a stepwise fashion at each *Time* that they are defined to change. The user must also verify the atmospheric relative concentration (dispersion), X/Q, to the intake. These values must exist at the inlet to the filter from the environment Multiple inlets to the same room will have the same X/Q. This capability is the only allowed transfer path from the environment. This option was exercised in acceptance test cases 14 and 14B. Clicking on **OK** or **CANCEL** will return the user to the **Select Transfer Pathway** menu (screen number 2400).

```
                        Scenario Description
                      Transfer Pathways: Filter
                          Air Intake X/Qs



                    Time              X/Q

                  ┌──────────┐    ┌──────────────┐
                  │ 0.0000   │    │ 0.2200E-02   │
                  │ 2.0000   │    │ 0.1500E-02   │
                  │ 8.0000   │    │ 0.1300E-02   │
                  │24.0000   │    │ 0.8400E-03   │
                  │96.0000   │    │ 0.4800E-03   │
                  └──────────┘    └──────────────┘




          ┌──────────┐              ┌──────────┐
          │    OK    │              │  CANCEL  │
          └──────────┘              └──────────┘
                                                    SN 2420T2
                        Time (hr).
```

The **Air Intake X/Qs** description is screen number 2420T2. This screen allows the user to input a set of X/Q (s/m^3) relative concentrations for the inlet. X/Q has also been referred to as the atmospheric dispersion coefficient because it is a measure of the spread of the released mass from the release point to the receptor inlet. NUREG/CR-6331 [Ra95] details a method of calculation. This input allows the fission product concentration to be drawn into a compartment. Because of the code structure, all inlets from the environment to a compartment must have the same X/Q. This option was used in all acceptance tests that had control rooms. The X/Q will change in a stepwise fashion at each time that it is defined to change. Clicking on **OK** or **CANCEL** will return the user to the **User-Specified Filter Parameters** menu (screen number 2420T).

```
┌─────────────────────────────────────────────────────────────────────┐
│ File  Review   Plant File = TEST24.PMF    Scenario File = TEST24.SDF   Help │
│                                                                       │
│                       Scenario Description                            │
│                 Transfer Pathways: Suppression Pool                   │
│                                                                       │
│                         Suppression Pool                              │
│                                                                       │
│                                                                       │
│         Select Models                    Edit Model Parameters        │
│      ┌────────────────────────┐    ┌────────────────────────────────┐ │
│      │ Aerosol          ( )   │    │ (1) Aerosol Removal            │ │
│      │                        │    └────────────────────────────────┘ │
│      │                        │    ┌────────────────────────────────┐ │
│      │ Elemental Iodine ( )   │    │ (2) Elemental Iodine Removal   │ │
│      │                        │    └────────────────────────────────┘ │
│      │                        │    ┌────────────────────────────────┐ │
│      │ Organic Iodine   ( )   │    │ (3) Organic Iodine Removal     │ │
│      └────────────────────────┘    └────────────────────────────────┘ │
│                                    ┌────────────────────────────────┐ │
│                                    │ (4) Return to Transfer Pathways Menu │ │
│                                    └────────────────────────────────┘ │
│                                                                       │
│                                                          SN 2430      │
└─────────────────────────────────────────────────────────────────────┘
```

The **Transfer Pathways: Suppression Pool** menu is screen number 2430. This screen allows the user to include information on the removal of fission products by passing through a *Suppression Pool*. The user may specify information on *Aerosol Removal, Elemental Iodine Removal*, or *Organic Iodine Removal* from the pool. Any or all removal methods may be chosen. If the user does not choose a removal mechanism, the default is for no removal. Selecting *Return to Transfer Pathways Menu* returns the user to the **Select Transfer Pathway** menu (screen number 2400).

Scenario Description
Transfer Pathways: Suppression Pool
Aerosol Removal: User-Specified Decontamination Factors

Suppression Pool

Time	Decontamination Factor	Flow Rate
0.0000	0.0000	0.0000E+00
0.0000	0.0000	0.0000E+00
0.0000	0.0000	0.0000E+00
0.0000	0.0000	0.0000E+00
0.0000	0.0000	0.0000E+00

OK   CANCEL

SN 2431T

Time (hr).

The **User-Specified Decontamination Factors** for aerosol removal are screen number 2431T. This allows the user to specify the time dependence of the aerosol decontamination factor for a particular aerosol flow rate in time. The *Decontamination Factor* and *Flow Rate* (cfm) will change in a stepwise fashion at each *Time* that they are defined to change. Decontamination factors are always ≥1.0. Clicking on **OK** or **CANCEL** will return the user to the **Transfer Pathways: Suppression Pool** menu (screen number 2430).

Scenario Description
Transfer Pathways: Suppression Pool
Elemental Iodine Removal: User-Specified Decontamination Factors

Suppression Pool

Time	Decontamination Factor	Flow Rate
0.0000	0.0000	0.0000E+00
0.0000	0.0000	0.0000E+00
0.0000	0.0000	0.0000E+00
0.0000	0.0000	0.0000E+00
0.0000	0.0000	0.0000E+00

OK   CANCEL

SN 2432T

Time(hr).

The **User-Specified Decontamination Factors** for elemental iodine removal are screen number 2432T. This screen allows the user to specify the time dependence of the elemental iodine decontamination factor for a particular elemental iodine flow rate (cfm) in time. The *Decontamination Factor* and *Flow Rate* will change in a stepwise fashion at each *Time* they are defined to change. A minimum value of 1.0 is required for the decontamination factor. Clicking on **OK** or **CANCEL** will return the user to the **Transfer Pathways: Suppression Pool** menu (screen number 2430).

Scenario Description
Transfer Pathways: Suppression Pool
Organic Iodine Removal: User-Specified Decontamination Factors

Suppression Pool

Time	Decontamination Factor	Flow Rate
0.0000	0.0000	0.0000E+00
0.0000	0.0000	0.0000E+00
0.0000	0.0000	0.0000E+00
0.0000	0.0000	0.0000E+00
0.0000	0.0000	0.0000E+00

OK   CANCEL

SN 2433T

Time (hr).

The **User-Specified Decontamination Factors** for organic iodine removal are screen number 2433T. This screen allows the user to specify the time dependence of the organic iodine decontamination factor for a particular organic iodine flow rate (cfm) in time. The *Decontamination Factor* and *Flow Rate* will change in a stepwise fashion at each *Time* they are defined to change. Clicking on **OK** or **CANCEL** will return the user to the **Transfer Pathways: Suppression Pool** menu (screen number 2430).

Scenario Description
Transfer Pathways: Air Leakage
User-Specified Air Leakage Rates

Unsprayed to Environment

Time

Leakage Rate

Time	Leakage Rate
0.0000	0.5000E-01
24.0000	0.2500E-01
0.0000	0.0000E+00
0.0000	0.0000E+00
0.0000	0.0000E+00

Select User Leakage Rates   Yes(■)   No( )

OK   CANCEL

SN 2440T

Time (hr).

The **User-Supplied Air Leakage Rates** are screen number 2440T. The screen allows the user to specify the time-dependent convective flow rate from one compartment to another. This is the typical path used for containment leakage. It was used in assessment test cases 1–10 and 19–24. A typical value is 0.12%/day for a PWR and 1.8%/day for a BWR. The leakage rate (%/day) will change in a stepwise fashion at each *Time* it is defined to change. The user must have the *Select User Leakage Rates* button on *Yes* for the code to use the tabular input. When it is set to *No*, the leak flow is always 0.0. Clicking on **OK** or **CANCEL** will return the user to the **Select Transfer Pathways** menu (screen number 2400).

Scenario Description
Dose Calculation Input

```
┌─────────────────────────────────────────┐
│ (1) Select Dose Conversion Factors      │
└─────────────────────────────────────────┘


┌─────────────────────────────────────────┐
│ (2) Create/Modify Dose Locations        │
└─────────────────────────────────────────┘


┌─────────────────────────────────────────┐
│ (3) Return to Scenario Description Menu  │
└─────────────────────────────────────────┘
```

SN 2500

The **Dose Calculation Input** menu is screen 2500. This screen allows the user access to the input that can affect the dose resulting from a known concentration. The user must go through each subscreen. Selecting *Return to Scenario Description Menu* returns the user to screen number 2000.

Scenario Description
Dose Calculation Input
Select Dose Conversion Factors

```
  ┌─────────────────────────────────────────────────────────────┐
  │    TID-14844 14 isotope              MACCS 60 isotope         │
  │ ( ) inventory, FGR 11 & 12      ( )  inventory, ICRP60        │
  │    dose conversion factors           dose conversion factors  │
  │                                                               │
  │    MACCS 60 isotope                  User defined             │
  │ (■) inventory, FGR 11 & 12      ( )  isotope inventory and    │
  │    dose conversion factors           dose conversion factors  │
  └─────────────────────────────────────────────────────────────┘
```

File Name | DEFAULTS\FGR60.INP | | EDIT |

| OK | | CANCEL |

SN 2510

Select dose conversion factor

The **Select Dose Conversion Factors** menu is screen 2510. This screen allows the user access to the dose conversion factors used to relate concentration and dose. Typical conversion factor tables are discussed in Section 1.4.3.4. Selecting a conversion table will return the user to the **Dose Calculation Input** menu (screen number 2500).

```
                       Scenario Description
                      Dose Calculation Input
                    Create/Modify Dose Locations

   ┌──────────────────────────────────────────────────────────────┐
   │  1│ Exclusion Area Boundary          │                        │
   │  2│ Low Population Zone              │                        │
   │  3│ Control Room                    │       ┌──────────┐      │
   │  4│ Unused                          │       │   EDIT   │      │
   │  5│ Unused                          │       └──────────┘      │
   │  6│                                 │                        │
   │  7│                                 │                        │
   │  8│                                 │       ┌──────────┐      │
   │  9│                                 │       │    OK    │      │
   │ 10│                                 │       └──────────┘      │
   └──────────────────────────────────────────────────────────────┘

                                                            SN 2520
      Select dose location to edit, then enter return or press EDIT.
```
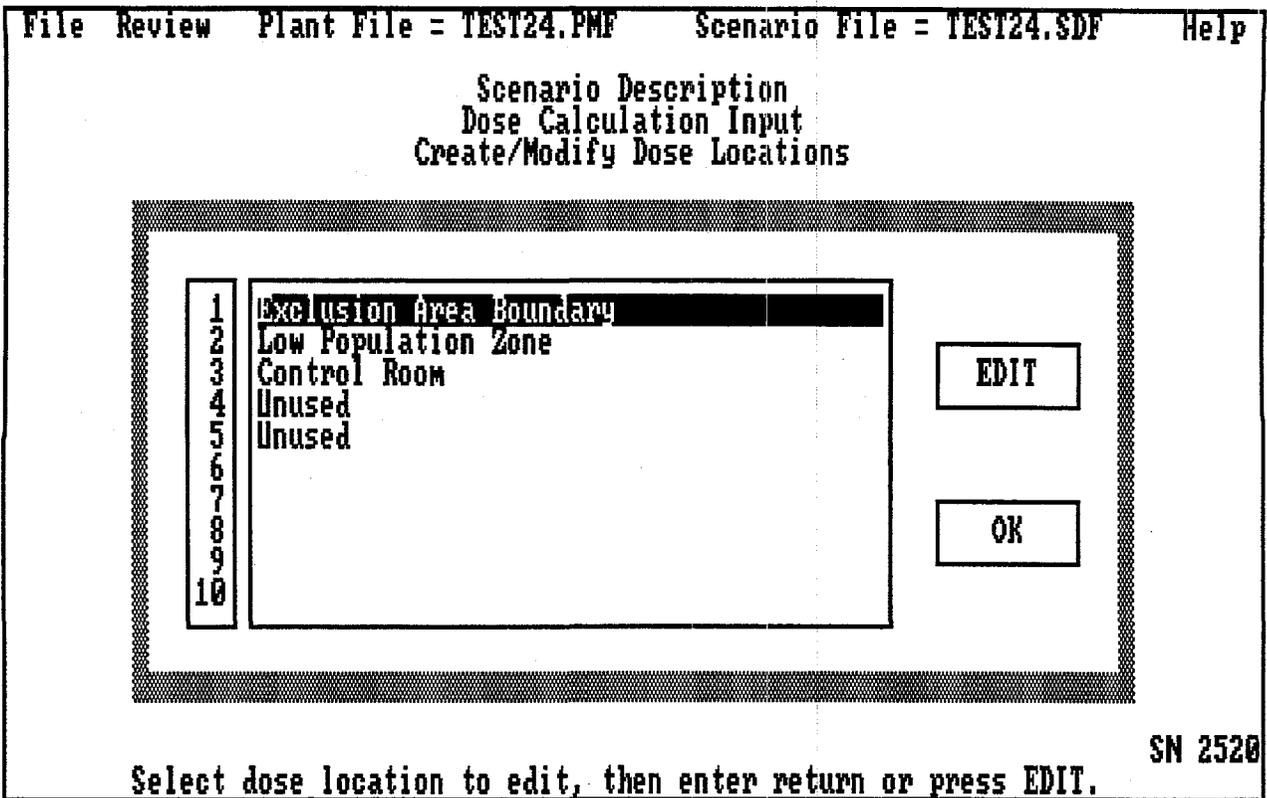
The **Create/Modify Dose Locations** selection menu is screen number 2520. This screen allows the user to access the locations where dose calculations are to be performed. It is invoked when the user selects (5) on the **Scenario Description** menu. The user will specify unique names for each of the locations. Highlighting the next "Unused" and clicking an **EDIT** will transfer control to a subscreen in which more detailed information is entered for that specific location. Clicking on **OK** will return the user to the **Dose Calculation Input** menu (screen number 2500).

Scenario Description
Dose Calculation Input
Create/Modify Dose Locations

Location Name

| Exclusion Area Boundary |

Compartment Name

| Environment |

Selected
Compartment Type

( ) Control Room

(■) Environment

( ) Other

| Edit Dose Location Parameters |

| OK | | CANCEL |

SN 2520A

Enter or edit a name for this dose location.

The **Create/Modify Dose Locations** are screen number 2520A, This screen allows the user to input dose information for a particular location, for example, the low population zone. The *Location Name* is chosen by the user and will be listed on the output file when detailing dose results. The compartment that contains the location is chosen from the list of compartments that is obtained by double clicking on the *Compartment Name* and will bring up the subscreen list. Clicking on **OK** or **CANCEL** will return the user to the **Create/Modify Dose Locations** selection menu (screen number 2500).

Scenario Description
Dose Calculation Input
Create/Modify Dose Location: Location Compartment

1	Sprayed Region
2	Unsprayed Region
3	Annulus
4	Environment
5	Control Room
6	Unused
7	Unused
8	Unused
9	Unused
10	Unused

OK

CANCEL

SN 2521

Click on name to edit name - double click to edit parameters.

The **Create/Modify Dose Location: Location Compartment** menu is screen number 2521. It allows the user to select a plant model compartment within which a dose is located. Clicking on **OK** or CANCEL will return the user to the **Create/Modify Dose Locations** menu (screen number 2520A).

Scenario Description
Dose Calculation Inputs
Create/Modify Dose Location: Control Room

Control Room

Occupancy Factors   Breathing Rates

Time   Factor   Time   Rate

0.0000	1.0000	0.0000	0.3470E-03
24.0000	0.6000	720.0000	0.0000E+00
96.0000	0.4000	0.0000	0.0000E+00
720.0000	0.0000	0.0000	0.0000E+00
0.0000	0.0000	0.0000	0.0000E+00

Use DBA Occupancy Factors ⟨ ⟩   Use DBA Breathing Rates ⟨ ⟩

OK   CANCEL

SN 2522

Time (hr).

The **Create/Modify Dose Location: Control Room** is screen number 2522. This screen allows the user to input occupancy factors and breathing rates for a control room. The fission products typically enter through inlets. The X/Qs to all the inlets to a control room are a constant set of time-dependent values as given on screen number 2420T2. The *Breathing Rates* (m^3/s) and *Occupancy Factors* will change in a stepwise fashion each time they are defined to change. Clicking on **OK** or on **CANCEL** will return the user to the **Create/Modify Dose Location** screen (screen number 2520A).

Scenario Description
Dose Calculation Input
Create/Modify Location Parameters: Environment

Exclusion Area Boundary

Atmospheric Relative
Concentrations

Time	X/Q
0.0000	0.1000E-02
2.0000	0.0000E+00
0.0000	0.0000E+00
0.0000	0.0000E+00
0.0000	0.0000E+00

Breathing Rates

Time	Rate
0.0000	0.3470E-03
8.0000	0.1750E-03
24.0000	0.2320E-03
0.0000	0.0000E+00
0.0000	0.0000E+00

(*) Use DBA Breathing Rates
Location: (•)EAB ( )LPZ

OK   CANCEL

SN 2523

Time (hr).

The **Create/Modify Location Parameters: Environment** description is screen number 2523. This screen allows the user to input the *Atmospheric Relative Concentration* for the environment location where a dose will be calculated. This screen is activated by selecting an environment dose and double clicking on the *Edit Dose Location Parameters* pad of screen 2520A. This is typically for the low population zone or exclusion area boundary. Values for X/Q vary with reactor and may be calculated using models similar to those in ARCON [Ra95]. The X/Q (s/m^3) and *Breathing Rate* (m^3/s) will change in a stepwise fashion at each time they are defined to change. Clicking on **OK** or **CANCEL** will return the user to the **Create/Modify Dose Locations** menu (screen number 2520A).

```
 File  Review   Plant File = TEST24.PMF     Scenario File = TEST24.SDF    Help

 Review Scenario Description -- Press the ESC key to exit.             SN 2600

  ####################################################################### ↑
                RADTRAD Version 2.20  12/20/97 13:23:16.73
  #######################################################################

  #######################################################################
                            File information
  #######################################################################

  Plant file name          = ACCEPT\TEST24.PMF
  Inventory file name      = DEFAULTS\PWR_DEF.NIF
  Scenario file name       = ACCEPT\TEST24.SDF
  Release file name        = DEFAULTS\PWR_DBA.RFT
  Dose conversion file name = DEFAULTS\FGR60.INP


  #######################################################################
                          Scenario Description
  #######################################################################                              ↓
```

The **Review Scenario Description** is screen number 2600. This screen allows the user to review
the current scenario. The user returns to the **Scenario Description** menu (screen 2000) by using
the escape key (ESC) on the keyboard.

```
                          Scenario Description
                       Save Scenario Description




          Enter path and file name of Scenario Description
        ┌──────────────────────────────────────────────────────┐
        │ ACCEPT\TEST24.SDF                                     │
        └──────────────────────────────────────────────────────┘






        ┌────────────────┐              ┌────────────────┐
        │      OK        │              │     CANCEL     │
        └────────────────┘              └────────────────┘
                                                            SN 2700
            The file name can be up to 40 characters long.
```

The **Save Scenario Description** is screen number 2700. This screen allows the user to specify a file name for the scenario description. It is invoked when the user selects *Save Scenario Description* on screen 2000. Note the convention of XXX.SDF where XXX is the user description and SDF stands for scenario description file. Clicking on **OK** or **CANCEL** will return the user to the **Scenario Description** menu (screen number 2000).

```
                          Calculate Results

        Supplemental               Enter Name of Output File
        Time Steps              ┌──────────────────────────────────┐
                                │ACCEPT\TEST24.TXT                 │
   Time          Time Step      └──────────────────────────────────┘
 ┌─────────┐   ┌─────────┐      Show Results
 │ 0.0000  │   │ 0.0500  │      ┌──────────────────────────────────┐
 │ 3.0000  │   │ 0.2500  │      │(*)For Every Simulation Event     │
 │ 8.0000  │   │ 1.0000  │      │( )For Every Supplemental Time Step│
 │24.0000  │   │ 4.0000  │      │( )Include Run-Time Model Information│
 │720.0000 │   │ 0.0000  │      │(*)Plant Model  (*)Scenario Description│
 └─────────┘   └─────────┘      └──────────────────────────────────┘

   Percent      ┌───────────────────────────────┐      ┌───────────┐
   Complete     │                               │      │ CALCULATE │
                └───────────────────────────────┘      └───────────┘
                0%              50%          100%

            ┌────────┐                ┌────────┐
            │   OK   │                │ CANCEL │          SN 3000
            └────────┘                └────────┘
           The file name can be up to 40 characters long.
```

The **Calculate Results** menu is screen number 3000. This screen allows the user to control the execution of the code and output. The time step tables allow intermediate (supplemental) results to be calculated by making the time steps finer, for example:

Time	Time Step
0.0	0.25
4.0	1.0
24.0	4.0
720.0	0

With the table shown, the error will probably decrease by 10–15%, at some increase in time. If a more accurate result is required, reduce the step accordingly, perhaps running the entire transient at 0.25 hr. However, this will significantly increase the running time.

It is recommended that the user adjust his output file name to match the PMF and SDF files used as input, perhaps XXX.TXT. The *Show Results* box controls the output and is explained in Section 1.5. The dose results are shown *For Every Simulation Event* if it is checked. Time step results can be edited by clicking the *For Every Supplemental Time Step* button. The *Include Run Time Model Information* option edits the effective removal coefficient for any models (such as the Powers spray model) that are active. The *Plant Model* and *Scenario Description* options edit the input on the output file when selected. The *Percent Complete* tab will go from light to dark as the calculation proceeds and allows the user to see how quickly the results are calculated. The user must click on **CALCULATE** to start the run. Clicking on **OK** or on **CANCEL** will return the user to the **Main** menu (screen number 0000).

```
┌──────────────────────────────────────────────────────────────────┐
│ File  Review   Plant File = TEST24.PMF    Scenario File = TEST24.SDF  Help │
│                        Examine Results                              │
│                                                                    │
│                                                                    │
│                                                                    │
│      Enter the output file name                                    │
│      ┌─────────────────────────────────┐    ┌───────────┐          │
│      │ACCEPT\TEST24.TXT                │    │ EXAMINE   │          │
│      └─────────────────────────────────┘    └───────────┘          │
│                                                                    │
│                                                                    │
│                                                                    │
│           ┌───────────┐            ┌───────────┐                   │
│           │    OK     │            │  CANCEL   │                   │
│           └───────────┘            └───────────┘                   │
│                                                          SN 4000    │
│              The file name can be up to 40 characters long.         │
└──────────────────────────────────────────────────────────────────┘
```

The **Examine Results** menu is screen number 4000. This screen allows the user to edit a file, usually the output file. This screen can also be used as another way into the file directories with the ability to scan any file without leaving RADTRAD. Clicking on **OK** or **CANCEL** will return the user to the **Main** menu (screen number 0000).

```
 File  Review   Plant File = TEST24.PMF     Scenario File = TEST24.SDF      Help

 Examine Output File: ACCEPT\TEST24.TXT -- Press the ESC key to exit.     SN 4100

 ┌────────────────────────────────────────────────────────────────────────┐ ┌─┐
 │ ###################################################################### │ │↑│
 │                 RADTRAD Version 2.20  12/20/97 13:27:12.69             │ │▓│
 │ ###################################################################### │ │▓│
 │                                                                        │ │▓│
 │ ###################################################################### │ │▓│
 │                         File information                               │ │▓│
 │ ###################################################################### │ │▓│
 │                                                                        │ │▓│
 │ Plant file name         = ACCEPT\TEST24.PMF                            │ │▓│
 │ Inventory file name     = DEFAULTS\PWR_DEF.NIF                         │ │▓│
 │ Scenario file name      = ACCEPT\TEST24.SDF                            │ │▓│
 │ Release file name       = DEFAULTS\PWR_DBA.RFT                         │ │▓│
 │ Dose conversion file name = DEFAULTS\FGR60.INP                         │ │▓│
 │                                                                        │ │▓│
 │ ###################################################################### │ │▓│
 │                         Plant Description                              │ │▓│
 │ ###################################################################### │ │▓│
 │                                                                        │ │▓│
 │ Number of Nuclides =  60                                               │ │↓│
 └────────────────────────────────────────────────────────────────────────┘ └─┘
```

The **Examine Output File** is screen number 4100. This screen allows the user to examine the
output in the output file by use of the scroll bar on the right-hand side of the screen. Return to the
Examine Results screen (screen number 4000) is by using the escape key (ESC) on the keyboard.

```
 File  Review   Plant File = TEST24.PMF      Scenario File = TEST24.SDF     Help

                              Exit RADTRAD



                   Enter path and file name of Plant Model

         Do Not Save ( )  |ACCEPT\TEST24.PMF                    |



                   Enter path and file name of Scenario Description

         Do Not Save ( )  |ACCEPT\TEST24.SDF                    |




              |    OK    |                    |  CANCEL  |
                                                                  SN 5000
              The file name can be up to 40 characters long.
```

Exit RADTRAD is screen number 5000. Entering the names and clicking on **OK** will result in the plant model and/or scenario descriptions being saved to those files. Clicking on the *Do Not Save* tab and then clicking on **OK** will result in the information not being saved. Clicking on **OK** will return the user to the DOS command line, terminating RADTRAD. Clicking on **CANCEL** will return the user to the **Main** menu (screen number 0000).

1.4.3 Files Associated with the Source Term

RADTRAD supports two sources for postulated releases of fission products: "Calculation of Distance Factors for Power and Test Reactor Sites," TID-14844 [Di62], and "Accident Source Terms for Light-Water Nuclear Power Plants," NUREG-1465 [So95]. These documents detail timing and release fractions of particular elemental fission products for postulated accidents. The elemental release to dose consequence calculation requires that a particular isotopic distribution be known. In the sections that follow, the release fraction data are described, then the nuclide half-life list, then sample inventories [Ca93], and then standard inventory to dose files [FGR11 and 12]. All of these files are stored as part of the defaults subdirectory when loading the code as described in Sections 1.1.1 or 1.1.2.

1.4.3.1 Release Fraction and Timing Files

Five release fraction and timing tables are normally used by RADTRAD. Chronologically, the oldest release pattern is that described in TID-14844 [Di62]. This pattern is a puff release of all the nobles and a fraction of the iodines. It is detailed in Table 1.4.3.1-1.

Tables 1.4.3.1-2 and 1.4.3.1-3 detail the release fractions and timing for a severe accident in either a PWR or a BWR as given in NUREG-1465. In these cases, a fraction of the core inventory is released during four time periods: gap, early in-vessel, ex-vessel, and late in-vessel. The last two occur simultaneously but the latter occurs for an extended period of time. Note that the difference between a design basis accident (DBA) and a severe accident is timing. In the DBA scenario, the vessel does not fail, so the last two release periods are excluded. Thus there are two PWR-1465 files: PWR_DEF, which uses four release periods, and PWR_DBA, which uses the first two. A similar pattern exists for the BWR files.

Table 1.4.3.1-1 TID Release Fraction and Timing

```
Release Fraction and Timing Name:
TID, TID-14844, Table IV., w/Reg Guide 1.3 & 1.4 Mods
```

CHEMICAL GROUP	GAP	DURATION (hr) In-Vessel	Ex-Vessel	Late In-Vessel
	0.1000E-01	0.0000E+00	0.0000E+00	0.0000E+00
1. Noble Gases:	0.1000E+01	0.0000E+00	0.0000E+00	0.0000E+00
2. Iodine:	0.2500E+00	0.0000E+00	0.0000E+00	0.0000E+00
3. Cesium:	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4. Tellurium:	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
5. Strontium:	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
6. Barium:	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
7. Ruthenium:	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
8. Cerium:	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
9. Lanthanum:	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Nonradioactive aerosols (kg):	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

```
End of Release File
```

Note: These values are stored as file "TID_DEF.RFT"

Table 1.4.3.1-2 PWR-NUREG-1465 Release Fraction and Timing

Release Fraction of Core Inventories and Timings:
PWR, NUREG-1465, Tables 3.13, February 1995

CHEMICAL GROUP	GAP	DURATION (hr) In-Vessel	Ex-Vessel	Late In-Vessel
	0.5000E+00	0.1300E+01	0.2000E+01	0.1000E+02
1. Noble Gases:	0.5000E-01	0.9500E+00	0.0000E+00	0.0000E+00
2. Iodine:	0.5000E-01	0.3500E+00	0.2500E+00	0.1000E+00
3. Cesium:	0.5000E-01	0.2500E+00	0.3500E+00	0.1000E+00
4. Tellurium:	0.0000E+00	0.0500E+00	0.2500E+00	0.5000E-02
5. Strontium:	0.0000E+00	0.2000E-01	0.1000E+00	0.0000E+00
6. Barium:	0.0000E+00	0.2000E-01	0.1000E+00	0.0000E+00
7. Ruthenium:	0.0000E+00	0.2500E-02	0.2500E-03	0.0000E+00
8. Cerium:	0.0000E+00	0.5000E-03	0.5000E-02	0.0000E+00
9. Lanthanum:	0.0000E+00	0.2000E-03	0.5000E-02	0.0000E+00
10. Nonradioactive aerosols (kg):	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Note: These values are stored in file "PWR_DEF.RFT." A similar file with 0.0 for all values in the last 2 columns representing a design basis release is stored in file "PWR_DBA.RFT."

Table 1.4.3.1-3 BWR NUREG-1465 Release Fraction and Timing

Release Fraction of Core Inventory and Timings:

BWR, NUREG-1465, Table 3.12
February 1995

CHEMICAL GROUP	GAP	In-Vessel	DURATION (hr) Ex-Vessel	Late In-Vessel
	0.5000E+00	0.1500E+01	0.3000E+01	0.1000E+02
1. Noble Gases:	0.5000E-01	0.9500E+00	0.0000E+00	0.0000E+00
2. Iodine:	0.5000E-01	0.2500E+00	0.3000E+00	0.1000E-01
3. Cesium:	0.5000E-01	0.2000E+00	0.3500E+00	0.1000E-01
4. Tellurium:	0.0000E+00	0.5000E-01	0.2500E+00	0.5000E-02
5. Strontium:	0.0000E+00	0.2000E-01	0.1000E+00	0.0000E+00
6. Barium:	0.0000E+00	0.2000E-01	0.1000E+00	0.0000E+00
7. Ruthenium:	0.0000E+00	0.2500E-02	0.2500E-02	0.0000E+00
8. Cerium:	0.0000E+00	0.5000E-03	0.5000E-02	0.0000E+00
9. Lanthanum:	0.0000E+00	0.2000E-03	0.5000E-02	0.0000E+00
10. Nonradioactive aerosols (kg):	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Note: These values are stored in file "BWR_DEF.RFT." A similar file with 0.0 for all values in the last 2 columns representing a design basis release is stored in file "BWR_DBA.RFT."

1.4.3.2 Nuclide Inventory

The initial mass (c_i) of each isotope is required to calculate a dose. Given the initial mass and a fractional release, the concentration of an isotope at a location can be determined. The masses are stored in these tables as a function of the reactor power so they can be adjusted for the power level of the reactor under consideration. The fractional releases are given in the previous section as a function of the chemical group, and within these tables, the chemical group as a function of the isotope is given. These tables were also used to relate the isotope to the element and to provide decay and daughter data. The data have been taken from the TID-14844 report and from sample calculations used by MACCS [Ch 90] that are based upon ORIGEN calculations.

There are three default files: the 14-isotope, 3-element TID-14844-related data (Table 1.4.3.2-1) and the PWR and BWR 60-isotope, 9-element NUREG-1465 data (Tables 1.4.3.2-2.3). The isotopes chosen are those selected in WASH-1400 [75] with the additional 6 isotopes added by Alpert [A186] and used in the MACCS code [Ch90]. In addition to the TID and NUREG-1465 sample inventories, a set of inventories containing only ^{131}I is also stored in the defaults subdirectory.

The structure of the files is:
 Nuclide inventory name
   NUREG or TID
 Power level
   1.0 Normalized core power
 Number of nuclides
   XX
 Nuclide number
   Isotope
   Chemical group (from Tables 1.4.3.1-1.3)
   Half-life
   Atomic weight
   Inventory/Power (Ci/MWth)
   Daughter isotope Fraction
   Daughter isotope Fraction
   Daughter isotope Fraction

 Next Nuclide Number

Table 1.4.3.2-1

```
Nuclide Inventory Name:
TID-14844 Example Normalized Core Inventory
Power Level:
 0.1000E+01
Nuclides:
 14
Nuclide 001:
I-131
   2
 0.6946560000E+06
 0.1310E+03
 0.2453E+05
Xe-131m   0.1100E-01
none                       0.0000E+00
none                       0.0000E+00
Nuclide 002:
I-132
   2
 0.8280000000E+04
 0.1320E+03
 0.9527E+05
none                       0.0000E+00
none                       0.0000E+00
none                       0.0000E+00
Nuclide 003:
I-133
   2
 0.7488000000E+05
 0.1330E+03
 0.5651E+05
Xe-133m            0.2900E-01
Xe-133             0.9700E+00
none                       0.0000E+00
Nuclide 004:
I-134
   2
 0.3156000000E+04
 0.1340E+03
 0.6445E+05
none                       0.0000E+00
none                       0.0000E+00
none                       0.0000E+00
Nuclide 005:
I-135
   2
 0.2379600000E+05
 0.1350E+03
 0.5225E+05
Xe-135m            0.1500E+00
Xe-135             0.8500E+00
none                       0.0000E+00
Nuclide 006:
Xe-131m
   1
 0.1028160000E+07
 0.1310E+03
 0.2487E+03
none                       0.0000E+00
```

```
none                     0.0000E+00
none                     0.0000E+00
Nuclide 007:
Xe-133m
   1
 0.1890432000E+06
 0.1330E+03
 0.1346E+04
Xe-133            0.1000E+01
none                     0.0000E+00
none                     0.0000E+00
Nuclide 008:
Xe-133
   1
 0.4531680000E+06
 0.1330E+03
 0.5572E+05
none                     0.0000E+00
none                     0.0000E+00
none                     0.0000E+00
Nuclide 009:
Xe-135m
   1
 0.9174000000E+03
 0.1350E+03
 0.1528E+05
Xe-135            0.1000E+01
Cs-135            0.4500E-04
none                     0.0000E+00
Nuclide 010:
Xe-135
   1
 0.3272400000E+05
 0.1350E+03
 0.5027E+05
Cs-135            0.1000E+01
none                     0.0000E+00
none                     0.0000E+00
Nuclide 011:
Kr-83m
   1
 0.6588000000E+04
 0.8300E+02
 0.8581E+04
none                     0.0000E+00
none                     0.0000E+00
none                     0.0000E+00
Nuclide 012:
Kr-85m
   1
 0.1612800000E+05
 0.8500E+02
 0.1169E+05
Kr-85             0.2100E+00
none                     0.0000E+00
none                     0.0000E+00
Nuclide 013:
Kr-87
   1
 0.4578000000E+04
 0.8700E+02
```

```
  0.6541E+04
Rb-87                   0.1000E+01
none                    0.0000E+00
none                    0.0000E+00
Nuclide 014:
Kr-88
   1
  0.1022400000E+05
  0.8800E+02
  0.3297E+05
Rb-88                   0.1000E+01
none                    0.0000E+00
none                    0.0000E+00
End of Nuclear Inventory File
```
Note: These values are stored as file "TID_DEF.NIF."

Table 1.4.3.2-2

```
Nuclide Inventory Name:
 Normalized MACCS Sample 3412 MWth PWR Core Inventory
 Power Level:
  0.1000E+01
 Nuclides:
  60
 Nuclide 001:
 Co-58
    7
  0.6117120000E+07
  0.5800E+02
  0.2553E+03
 none                        0.0000E+00
 none                        0.0000E+00
 none                        0.0000E+00
 Nuclide 002:
 Co-60
    7
  0.1663401096E+09
  0.6000E+02
  0.1953E+03
 none                        0.0000E+00
 none                        0.0000E+00
 none                        0.0000E+00
 Nuclide 003:
 Kr-85
    1
  0.3382974720E+09
  0.8500E+02
  0.1960E+03
 none                        0.0000E+00
 none                        0.0000E+00
 none                        0.0000E+00
 Nuclide 004:
 Kr-85m
    1
  0.1612800000E+05
  0.8500E+02
  0.9181E+04
 Kr-85                       0.2100E+00
 none                        0.0000E+00
 none                        0.0000E+00
 Nuclide 005:
 Kr-87
    1
  0.4578000000E+04
  0.8700E+02
  0.1678E+05
 Rb-87                       0.1000E+01
 none                        0.0000E+00
 none                        0.0000E+00
 Nuclide 006:
 Kr-88
    1
  0.1022400000E+05
  0.8800E+02
  0.2269E+05
 Rb-88                       0.1000E+01
```

```
none                      0.0000E+00
none                      0.0000E+00
Nuclide 007:
Rb-86
    3
  0.1612224000E+07
  0.8600E+02
  0.1496E+02
none                      0.0000E+00
none                      0.0000E+00
none                      0.0000E+00
Nuclide 008:
Sr-89
    5
  0.4363200000E+07
  0.8900E+02
  0.2844E+05
none                      0.0000E+00
none                      0.0000E+00
none                      0.0000E+00
Nuclide 009:
Sr-90
    5
  0.9189573120E+09
  0.9000E+02
  0.1535E+04
Y-90                      0.1000E+01
none                      0.0000E+00
none                      0.0000E+00
Nuclide 010:
Sr-91
    5
  0.3420000000E+05
  0.9100E+02
  0.3656E+05
Y-91m                     0.5800E+00
Y-91                      0.4200E+00
none                      0.0000E+00
Nuclide 011:
Sr-92
    5
  0.9756000000E+04
  0.9200E+02
  0.3805E+05
Y-92                      0.1000E+01
none                      0.0000E+00
none                      0.0000E+00
Nuclide 012:
Y-90
    9
  0.2304000000E+06
  0.9000E+02
  0.1647E+04
none                      0.0000E+00
none                      0.0000E+00
none                      0.0000E+00
Nuclide 013:
Y-91
    9
  0.5055264000E+07
  0.9100E+02
```

```
     0.3465E+05
none                         0.0000E+00
none                         0.0000E+00
none                         0.0000E+00
Nuclide 014:
Y-92
    9
  0.1274400000E+05
  0.9200E+02
  0.3819E+05
none                         0.0000E+00
none                         0.0000E+00
none                         0.0000E+00
Nuclide 015:
Y-93
    9
  0.3636000000E+05
  0.9300E+02
  0.4320E+05
Zr-93                        0.1000E+01
none                         0.0000E+00
none                         0.0000E+00
Nuclide 016:
Zr-95
    9
  0.5527872000E+07
  0.9500E+02
  0.4377E+05
Nb-95m                       0.7000E-02
Nb-95                        0.9900E+00
none                         0.0000E+00
Nuclide 017:
Zr-97
    9
  0.6084000000E+05
  0.9700E+02
  0.4562E+05
Nb-97m                       0.9500E+00
Nb-97                        0.5300E-01
none                         0.0000E+00
Nuclide 018:
Nb-95
    9
  0.3036960000E+07
  0.9500E+02
  0.4138E+05
none                         0.0000E+00
none                         0.0000E+00
none                         0.0000E+00
Nuclide 019:
Mo-99
    7
  0.2376000000E+06
  0.9900E+02
  0.4830E+05
Tc-99m                       0.8800E+00
Tc-99                        0.1200E+00
none                         0.0000E+00
Nuclide 020:
Tc-99m
    7
```

```
  0.2167200000E+05
  0.9900E+02
  0.4169E+05
Tc-99                    0.1000E+01
none                     0.0000E+00
none                     0.0000E+00
Nuclide 021:
Ru-103
    7
  0.3393792000E+07
  0.1030E+03
  0.3598E+05
Rh-103m                  0.1000E+01
none                     0.0000E+00
none                     0.0000E+00
Nuclide 022:
Ru-105
    7
  0.1598400000E+05
  0.1050E+03
  0.2340E+05
Rh-105                   0.1000E+01
none                     0.0000E+00
none                     0.0000E+00
Nuclide 023:
Ru-106
    7
  0.3181248000E+08
  0.1060E+03
  0.8175E+04
Rh-106                   0.1000E+01
none                     0.0000E+00
none                     0.0000E+00
Nuclide 024:
Rh-105
    7
  0.1272960000E+06
  0.1050E+03
  0.1621E+05
none                     0.0000E+00
none                     0.0000E+00
none                     0.0000E+00
Nuclide 025:
Sb-127
    4
  0.3326400000E+06
  0.1270E+03
  0.2208E+04
Te-127m                  0.1800E+00
Te-127                   0.8200E+00
none                     0.0000E+00
Nuclide 026:
Sb-129
    4
  0.1555200000E+05
  0.1290E+03
  0.7820E+04
Te-129m                  0.2200E+00
Te-129                   0.7700E+00
none                     0.0000E+00
Nuclide 027:
```

```
Te-127
   4
 0.3366000000E+05
 0.1270E+03
 0.2132E+04
none                      0.0000E+00
none                      0.0000E+00
none                      0.0000E+00
Nuclide 028:
Te-127m
   4
 0.9417600000E+07
 0.1270E+03
 0.2823E+03
Te-127                    0.9800E+00
none                      0.0000E+00
none                      0.0000E+00
Nuclide 029:
Te-129
   4
 0.4176000000E+04
 0.1290E+03
 0.7341E+04
I-129                     0.1000E+01
none                      0.0000E+00
none                      0.0000E+00
Nuclide 030:
Te-129m
   4
 0.2903040000E+07
 0.1290E+03
 0.1935E+04
Te-129                    0.6500E+00
I-129                     0.3500E+00
none                      0.0000E+00
Nuclide 031:
Te-131m
   4
 0.1080000000E+06
 0.1310E+03
 0.3707E+04
Te-131                    0.2200E+00
I-131                     0.7800E+00
none                      0.0000E+00
Nuclide 032:
Te-132
   4
 0.2815200000E+06
 0.1320E+03
 0.3690E+05
I-132                     0.1000E+01
none                      0.0000E+00
none                      0.0000E+00
Nuclide 033:
I-131
   2
 0.6946560000E+06
 0.1310E+03
 0.2540E+05
Xe-131m                   0.1100E-01
none                      0.0000E+00
```

```
none                          0.0000E+00
Nuclide 034:
I-132
    2
  0.8280000000E+04
  0.1320E+03
  0.3743E+05
none                          0.0000E+00
none                          0.0000E+00
none                          0.0000E+00
Nuclide 035:
I-133
    2
  0.7488000000E+05
  0.1330E+03
  0.5370E+05
Xe-133m                       0.2900E-01
Xe-133                        0.9700E+00
none                          0.0000E+00
Nuclide 036:
I-134
    2
  0.3156000000E+04
  0.1340E+03
  0.5893E+05
none                          0.0000E+00
none                          0.0000E+00
none                          0.0000E+00
Nuclide 037:
I-135
    2
  0.2379600000E+05
  0.1350E+03
  0.5063E+05
Xe-135m                       0.1500E+00
Xe-135                        0.8500E+00
none                          0.0000E+00
Nuclide 038:
Xe-133
    1
  0.4531680000E+06
  0.1330E+03
  0.5372E+05
none                          0.0000E+00
none                          0.0000E+00
none                          0.0000E+00
Nuclide 039:
Xe-135
    1
  0.3272400000E+05
  0.1350E+03
  0.1008E+05
Cs-135                        0.1000E+01
none                          0.0000E+00
none                          0.0000E+00
Nuclide 040:
Cs-134
    3
  0.6507177120E+08
  0.1340E+03
  0.3425E+04
```

```
none                        0.0000E+00
none                        0.0000E+00
none                        0.0000E+00
Nuclide 041:
Cs-136
    3
  0.1131840000E+07
  0.1360E+03
  0.1042E+04
none                        0.0000E+00
none                        0.0000E+00
none                        0.0000E+00
Nuclide 042:
Cs-137
    3
  0.9467280000E+09
  0.1370E+03
  0.1915E+04
Ba-137m                     0.9500E+00
none                        0.0000E+00
none                        0.0000E+00
Nuclide 043:
Ba-139
    6
  0.4962000000E+04
  0.1390E+03
  0.4976E+05
none                        0.0000E+00
none                        0.0000E+00
none                        0.0000E+00
Nuclide 044:
Ba-140
    6
  0.1100736000E+07
  0.1400E+03
  0.4924E+05
La-140                      0.1000E+01
none                        0.0000E+00
none                        0.0000E+00
Nuclide 045:
La-140
    9
  0.1449792000E+06
  0.1400E+03
  0.5032E+05
none                        0.0000E+00
none                        0.0000E+00
none                        0.0000E+00
Nuclide 046:
La-141
    9
  0.1414800000E+05
  0.1410E+03
  0.4615E+05
Ce-141                      0.1000E+01
none                        0.0000E+00
none                        0.0000E+00
Nuclide 047:
La-142
    9
  0.5550000000E+04
```

```
  0.1420E+03
  0.4449E+05
none                            0.0000E+00
none                            0.0000E+00
none                            0.0000E+00
Nuclide 048:
Ce-141
    8
  0.2808086400E+07
  0.1410E+03
  0.4476E+05
none                            0.0000E+00
none                            0.0000E+00
none                            0.0000E+00
Nuclide 049:
Ce-143
    8
  0.1188000000E+06
  0.1430E+03
  0.4352E+05
Pr-143                          0.1000E+01
none                            0.0000E+00
none                            0.0000E+00
Nuclide 050:
Ce-144
    8
  0.2456352000E+08
  0.1440E+03
  0.2697E+05
Pr-144m                         0.1800E-01
Pr-144                          0.9800E+00
none                            0.0000E+00
Nuclide 051:
Pr-143
    9
  0.1171584000E+07
  0.1430E+03
  0.4273E+05
none                            0.0000E+00
none                            0.0000E+00
none                            0.0000E+00
Nuclide 052:
Nd-147
    9
  0.9486720000E+06
  0.1470E+03
  0.1911E+05
Pm-147                          0.1000E+01
none                            0.0000E+00
none                            0.0000E+00
Nuclide 053:
Np-239
    8
  0.2034720000E+06
  0.2390E+03
  0.5120E+06
Pu-239                          0.1000E+01
none                            0.0000E+00
none                            0.0000E+00
Nuclide 054:
Pu-238
```

```
   8
 0.2768863824E+10
 0.2380E+03
 0.2902E+02
U-234                      0.1000E+01
none                       0.0000E+00
none                       0.0000E+00
Nuclide 055:
Pu-239
   8
 0.7594336440E+12
 0.2390E+03
 0.6545E+01
U-235                      0.1000E+01
none                       0.0000E+00
none                       0.0000E+00
Nuclide 056:
Pu-240
   8
 0.2062920312E+12
 0.2400E+03
 0.8254E+01
U-236                      0.1000E+01
none                       0.0000E+00
none                       0.0000E+00
Nuclide 057:
Pu-241
   8
 0.4544294400E+09
 0.2410E+03
 0.1390E+04
U-237                      0.2400E-04
Am-241                     0.1000E+01
none                       0.0000E+00
Nuclide 058:
Am-241
   9
 0.1363919472E+11
 0.2410E+03
 0.9181E+00
Np-237                     0.1000E+01
none                       0.0000E+00
none                       0.0000E+00
Nuclide 059:
Cm-242
   9
 0.1406592000E+08
 0.2420E+03
 0.3514E+03
Pu-238     0.1000E+01
none       0.0000E+00
none       0.0000E+00
Nuclide 060:
Cm-244
   9
 0.571508136E+9
 0.2440E+03
 0.2056E+02
Pu-240                     0.1000E+01
none                       0.0000E+00
none                       0.0000E+00
```

End of Nuclear Inventory File
Note: These values are stored in file "PWR_DEF.NIF."

Table 1.4.3.2-3

```
Nuclide Inventory Name:
Normalized MACCS Sample 3578 MWth BWR Core Inventory
Power Level:
 0.1000E+01
Nuclides:
 60
Nuclide 001:
Co-58
    7
 0.6117120000E+07
 0.5800E+02
 0.1529E+03
none                       0.0000E+00
none                       0.0000E+00
none                       0.0000E+00
Nuclide 002:
Co-60
    7
 0.1663401096E+09
 0.6000E+02
 0.1830E+03
none                       0.0000E+00
none                       0.0000E+00
none                       0.0000E+00
Nuclide 003:
Kr-85
    1
 0.3382974720E+09
 0.8500E+02
 0.2506E+03
none                       0.0000E+00
none                       0.0000E+00
none                       0.0000E+00
Nuclide 004:
Kr-85m
    1
 0.1612800000E+05
 0.8500E+02
 0.9110E+04
Kr-85                      0.2100E+00
none                       0.0000E+00
none                       0.0000E+00
Nuclide 005:
Kr-87
    1
 0.4578000000E+04
 0.8700E+02
 0.1657E+05
Rb-87                      0.1000E+01
none                       0.0000E+00
none                       0.0000E+00
Nuclide 006:
Kr-88
    1
 0.1022400000E+05
 0.8800E+02
 0.2236E+05
Rb-88                      0.1000E+01
```

```
none                              0.0000E+00
none                              0.0000E+00
Nuclide 007:
Rb-86
   3
  0.1612224000E+07
  0.8600E+02
  0.1402E+02
none                              0.0000E+00
none                              0.0000E+00
none                              0.0000E+00
Nuclide 008:
Sr-89
   5
  0.4363200000E+07
  0.8900E+02
  0.2774E+05
none                              0.0000E+00
none                              0.0000E+00
none                              0.0000E+00
Nuclide 009:
Sr-90
   5
  0.9189573120E+09
  0.9000E+02
  0.1963E+04
Y-90                              0.1000E+01
none                              0.0000E+00
none                              0.0000E+00
Nuclide 010:
Sr-91
   5
  0.3420000000E+05
  0.9100E+02
  0.3604E+05
Y-91m                             0.5800E+00
Y-91                              0.4200E+00
none                              0.0000E+00
Nuclide 011:
Sr-92
   5
  0.9756000000E+04
  0.9200E+02
  0.3765E+05
Y-92                              0.1000E+01
none                              0.0000E+00
none                              0.0000E+00
Nuclide 012:
Y-90
   9
  0.2304000000E+06
  0.9000E+02
  0.2102E+04
none                              0.0000E+00
none                              0.0000E+00
none                              0.0000E+00
Nuclide 013:
Y-91
   9
  0.5055264000E+07
  0.9100E+02
```

```
  0.3386E+05
none                        0.0000E+00
none                        0.0000E+00
none                        0.0000E+00
Nuclide 014:
Y-92
   9
  0.1274400000E+05
  0.9200E+02
  0.3780E+05
none                        0.0000E+00
none                        0.0000E+00
none                        0.0000E+00
Nuclide 015:
Y-93
   9
  0.3636000000E+05
  0.9300E+02
  0.4298E+05
Zr-93                       0.1000E+01
none                        0.0000E+00
none                        0.0000E+00
Nuclide 016:
Zr-95
   9
  0.5527872000E+07
  0.9500E+02
  0.4456E+05
Nb-95m                      0.7000E-02
Nb-95                       0.9900E+00
none                        0.0000E+00
Nuclide 017:
Zr-97
   9
  0.6084000000E+05
  0.9700E+02
  0.4587E+05
Nb-97m                      0.9500E+00
Nb-97                       0.5300E-01
none                        0.0000E+00
Nuclide 018:
Nb-95
   9
  0.3036960000E+07
  0.9500E+02
  0.4216E+05
none                        0.0000E+00
none                        0.0000E+00
none                        0.0000E+00
Nuclide 019:
Mo-99
   7
  0.2376000000E+06
  0.9900E+02
  0.4862E+05
Tc-99m                      0.8800E+00
Tc-99                       0.1200E+00
none                        0.0000E+00
Nuclide 020:
Tc-99m
   7
```

```
 0.2167200000E+05
 0.9900E+02
 0.4195E+05
Tc-99                      0.1000E+01
none                       0.0000E+00
none                       0.0000E+00
Nuclide 021:
Ru-103
   7
 0.3393792000E+07
 0.1030E+03
 0.3691E+05
Rh-103m                    0.1000E+01
none                       0.0000E+00
none                       0.0000E+00
Nuclide 022:
Ru-105
   7
 0.1598400000E+05
 0.1050E+03
 0.2458E+05
Rh-105                     0.1000E+01
none                       0.0000E+00
none                       0.0000E+00
Nuclide 023:
Ru-106
   7
 0.3181248000E+08
 0.1060E+03
 0.1002E+05
Rh-106                     0.1000E+01
none                       0.0000E+00
none                       0.0000E+00
Nuclide 024:
Rh-105
   7
 0.1272960000E+06
 0.1050E+03
 0.1835E+05
none                       0.0000E+00
none                       0.0000E+00
none                       0.0000E+00
Nuclide 025:
Sb-127
   4
 0.3326400000E+06
 0.1270E+03
 0.2324E+04
Te-127m                    0.1800E+00
Te-127                     0.8200E+00
none                       0.0000E+00
Nuclide 026:
Sb-129
   4
 0.1555200000E+05
 0.1290E+03
 0.8067E+04
Te-129m                    0.2200E+00
Te-129                     0.7700E+00
none                       0.0000E+00
Nuclide 027:
```

```
Te-127
   4
 0.3366000000E+05
 0.1270E+03
 0.2250E+04
none                          0.0000E+00
none                          0.0000E+00
none                          0.0000E+00
Nuclide 028:
Te-127m
   4
 0.9417600000E+07
 0.1270E+03
 0.3029E+03
Te-127                        0.9800E+00
none                          0.0000E+00
none                          0.0000E+00
Nuclide 029:
Te-129
   4
 0.4176000000E+04
 0.1290E+03
 0.7569E+04
I-129                         0.1000E+01
none                          0.0000E+00
none                          0.0000E+00
Nuclide 030:
Te-129m
   4
 0.2903040000E+07
 0.1290E+03
 0.1990E+04
Te-129                        0.6500E+00
I-129                         0.3500E+00
none                          0.0000E+00
Nuclide 031:
Te-131m
   4
 0.1080000000E+06
 0.1310E+03
 0.3821E+04
Te-131                        0.2200E+00
I-131                         0.7800E+00
none                          0.0000E+00
Nuclide 032:
Te-132
   4
 0.2815200000E+06
 0.1320E+03
 0.3735E+05
I-132                         0.1000E+01
none                          0.0000E+00
none                          0.0000E+00
Nuclide 033:
I-131
   2
 0.6946560000E+06
 0.1310E+03
 0.2581E+05
Xe-131m                       0.1100E-01
none                          0.0000E+00
```

```
none                       0.0000E+00
Nuclide 034:
I-132
   2
 0.8280000000E+04
 0.1320E+03
 0.3792E+05
none                       0.0000E+00
none                       0.0000E+00
none                       0.0000E+00
Nuclide 035:
I-133
   2
 0.7488000000E+05
 0.1330E+03
 0.5417E+05
Xe-133m                    0.2900E-01
Xe-133                     0.9700E+00
none                       0.0000E+00
Nuclide 036:
I-134
   2
 0.3156000000E+04
 0.1340E+03
 0.5930E+05
none                       0.0000E+00
none                       0.0000E+00
none                       0.0000E+00
Nuclide 037:
I-135
   2
 0.2379600000E+05
 0.1350E+03
 0.5099E+05
Xe-135m                    0.1500E+00
Xe-135                     0.8500E+00
none                       0.0000E+00
Nuclide 038:
Xe-133
   1
 0.4531680000E+06
 0.1330E+03
 0.5425E+05
none                       0.0000E+00
none                       0.0000E+00
none                       0.0000E+00
Nuclide 039:
Xe-135
   1
 0.3272400000E+05
 0.1350E+03
 0.1289E+05
Cs-135                     0.1000E+01
none                       0.0000E+00
none                       0.0000E+00
Nuclide 040:
Cs-134
   3
 0.6507177120E+08
 0.1340E+03
 0.4227E+04
```

```
none                           0.0000E+00
none                           0.0000E+00
none                           0.0000E+00
Nuclide 041:
Cs-136
    3
  0.1131840000E+07
  0.1360E+03
  0.1134E+04
none                           0.0000E+00
none                           0.0000E+00
none                           0.0000E+00
Nuclide 042:
Cs-137
    3
  0.9467280000E+09
  0.1370E+03
  0.2530E+04
Ba-137m                        0.9500E+00
none                           0.0000E+00
none                           0.0000E+00
Nuclide 043:
Ba-139
    6
  0.4962000000E+04
  0.1390E+03
  0.4994E+05
none                           0.0000E+00
none                           0.0000E+00
none                           0.0000E+00
Nuclide 044:
Ba-140
    6
  0.1100736000E+07
  0.1400E+03
  0.4927E+05
La-140                         0.1000E+01
none                           0.0000E+00
none                           0.0000E+00
Nuclide 045:
La-140
    9
  0.1449792000E+06
  0.1400E+03
  0.5027E+05
none                           0.0000E+00
none                           0.0000E+00
none                           0.0000E+00
Nuclide 046:
La-141
    9
  0.1414800000E+05
  0.1410E+03
  0.4642E+05
Ce-141                         0.1000E+01
none                           0.0000E+00
none                           0.0000E+00
Nuclide 047:
La-142
    9
  0.5550000000E+04
```

```
  0.1420E+03
  0.4466E+05
none                   0.0000E+00
none                   0.0000E+00
none                   0.0000E+00
Nuclide 048:
Ce-141
    8
  0.2808086400E+07
  0.1410E+03
  0.4473E+05
none                   0.0000E+00
none                   0.0000E+00
none                   0.0000E+00
Nuclide 049:
Ce-143
    8
  0.1188000000E+06
  0.1430E+03
  0.4355E+05
Pr-143                 0.1000E+01
none                   0.0000E+00
none                   0.0000E+00
Nuclide 050:
Ce-144
    8
  0.2456352000E+08
  0.1440E+03
  0.2901E+05
Pr-144m                0.1800E-01
Pr-144                 0.9800E+00
none                   0.0000E+00
Nuclide 051:
Pr-143
    9
  0.1171584000E+07
  0.1430E+03
  0.4263E+05
none                   0.0000E+00
none                   0.0000E+00
none                   0.0000E+00
Nuclide 052:
Nd-147
    9
  0.9486720000E+06
  0.1470E+03
  0.1905E+05
Pm-147                 0.1000E+01
none                   0.0000E+00
none                   0.0000E+00
Nuclide 053:
Np-239
    8
  0.2034720000E+06
  0.2390E+03
  0.5677E+06
Pu-239                 0.1000E+01
none                   0.0000E+00
none                   0.0000E+00
Nuclide 054:
Pu-238
```

```
     8
 0.2768863824E+10
 0.2380E+03
 0.3948E+02
U-234                        0.1000E+01
none                         0.0000E+00
none                         0.0000E+00
Nuclide 055:
Pu-239
     8
 0.7594336440E+12
 0.2390E+03
 0.1001E+02
U-235                        0.1000E+01
none                         0.0000E+00
none                         0.0000E+00
Nuclide 056:
Pu-240
     8
 0.2062920312E+12
 0.2400E+03
 0.1253E+02
U-236                        0.1000E+01
none                         0.0000E+00
none                         0.0000E+00
Nuclide 057:
Pu-241
     8
 0.4544294400E+09
 0.2410E+03
 0.2157E+04
U-237                        0.2400E-04
Am-241                       0.1000E+01
none                         0.0000E+00
Nuclide 058:
Am-241
     9
 0.1363919472E+11
 0.2410E+03
 0.2193E+01
Np-237                       0.1000E+01
none                         0.0000E+00
none                         0.0000E+00
Nuclide 059:
Cm-242
     9
 0.1406592000E+08
 0.2420E+03
 0.5791E+03
Pu-238                       0.1000E+01
none                         0.0000E+00
none                         0.0000E+00
Nuclide 060:
Cm-244
     9
 0.5715081360E+09
 0.2440E+03
 0.3125E+02
Pu-240                       0.1000E+01
none                         0.0000E+00
none                         0.0000E+00
```

End of Nuclear Inventory File

Note: These values are stored in file "PWR_DEF.NIF."

1.4.3.3 Conversion Factors File

The relationship between isotopic concentration and dose is detailed in Section 2.4.3. Using the method detailed requires the isotope concentration to dose relationship given in these files. These files correspond to the previous inventory files. The data were derived from Federal Guidance Reports 11 and 12 [FGR11, FGR12]. Table 1.3.3.3-1 contains the data for the 14-isotope, 3-element TID source term analysis. Table 1.3.3.3-2 gives similar information for the NUREG source term.

There are two files: the 14-isotope, 3-element TID-14844-related data and the 60-isotope, 9-element NUREG-1465 data. The structure of the files is:

> 2 title cards
> Number of organs
> > Organ list in alphanumeric form
> Number of nuclides
> > Nuclide list in alphanumeric form (half-life units also displayed)
>
> For each nuclide and for each organ
> > Dose conversion factors for 4 types of cloudshine, 2 inhalation, and 1 ingestion
> > (RADTRAD uses only the cloudshine, or submersion, and the inhalation effects).

Dose conversion factors (Sv/Bq) for inhalation and (Sv-s/Bq m^3) for submersion

Table 1.4.3.3-1 Dose Conversion Factors for TID-14844 Nuclides

```
FGRDCF 10/24/95   02:55:27   beta-test version 1.10, minor Fortran fixes 5/4/95
Implicit daughter half-lives (m) less than  90 and less than 0.100 of parent
          9 ORGANS DEFINED IN THIS FILE:
GONADS
BREAST
LUNGS
RED MARR
BONE SUR
THYROID
REMAINDER
EFFECTIVE
SKIN(FGR)
         14 NUCLIDES DEFINED IN THIS FILE:
I-131       D
I-132       D
I-133       D
I-134       D
I-135       D       Including:Xe-135m
Xe-131m
Xe-133m
Xe-133
Xe-135m
Xe-135
Kr-83m
Kr-85m
Kr-87
Kr-88
```

	CLOUDSHINE	GROUND SHINE 8HR	GROUND SHINE 7DAY	GROUND SHINE RATE	INHALED ACUTE	INHALED CHRONIC	INGESTION
I-131							
GONADS	1.780E-14	1.119E-11	1.789E-10	3.940E-16-1.000E+00	2.530E-11	4.070E-11
BREAST	2.040E-14	1.082E-11	1.730E-10	3.810E-16-1.000E+00	7.880E-11	1.210E-10
LUNGS	1.760E-14	1.016E-11	1.626E-10	3.580E-16-1.000E+00	6.570E-10	1.020E-10
RED MARR	1.680E-14	1.022E-11	1.635E-10	3.600E-16-1.000E+00	6.260E-11	9.440E-11
BONE SUR	3.450E-14	1.675E-11	2.679E-10	5.900E-16-1.000E+00	5.730E-11	8.720E-11
THYROID	1.810E-14	1.053E-11	1.685E-10	3.710E-16-1.000E+00	2.920E-07	4.760E-07
REMAINDER	1.670E-14	9.908E-12	1.585E-10	3.490E-16-1.000E+00	8.030E-11	1.570E-10
EFFECTIVE	1.820E-14	1.067E-11	1.707E-10	3.760E-16-1.000E+00	8.890E-09	1.440E-08
SKIN(FGR)	2.980E-14	1.825E-11	2.920E-10	6.430E-16-1.000E+00	0.000E+00	0.000E+00
I-132							
GONADS	1.090E-13	2.523E-11	2.771E-11	2.320E-15-1.000E+00	9.950E-12	2.330E-11
BREAST	1.240E-13	2.414E-11	2.652E-11	2.220E-15-1.000E+00	1.410E-11	2.520E-11
LUNGS	1.090E-13	2.305E-11	2.532E-11	2.120E-15-1.000E+00	2.710E-10	2.640E-11
RED MARR	1.070E-13	2.360E-11	2.592E-11	2.170E-15-1.000E+00	1.400E-11	2.460E-11
BONE SUR	1.730E-13	3.327E-11	3.655E-11	3.060E-15-1.000E+00	1.240E-11	2.190E-11
THYROID	1.120E-13	2.381E-11	2.616E-11	2.190E-15-1.000E+00	1.740E-09	3.870E-09
REMAINDER	1.050E-13	2.283E-11	2.509E-11	2.100E-15-1.000E+00	3.780E-11	1.650E-10
EFFECTIVE	1.120E-13	2.403E-11	2.640E-11	2.210E-15-1.000E+00	1.030E-10	1.820E-10
SKIN(FGR)	1.580E-13	8.199E-11	9.007E-11	7.540E-15-1.000E+00	0.000E+00	0.000E+00
I-133							
GONADS	2.870E-14	1.585E-11	6.748E-11	6.270E-16-1.000E+00	1.950E-11	3.630E-11
BREAST	3.280E-14	1.519E-11	6.468E-11	6.010E-16-1.000E+00	2.940E-11	4.680E-11
LUNGS	2.860E-14	1.446E-11	6.156E-11	5.720E-16-1.000E+00	8.200E-10	4.530E-11
RED MARR	2.770E-14	1.466E-11	6.242E-11	5.800E-16-1.000E+00	2.720E-11	4.300E-11
BONE SUR	4.870E-14	2.161E-11	9.202E-11	8.550E-16-1.000E+00	2.520E-11	4.070E-11
THYROID	2.930E-14	1.502E-11	6.393E-11	5.940E-16-1.000E+00	4.860E-08	9.100E-08
REMAINDER	2.730E-14	1.418E-11	6.038E-11	5.610E-16-1.000E+00	5.000E-11	1.550E-10
EFFECTIVE	2.940E-14	1.509E-11	6.425E-11	5.970E-16-1.000E+00	1.580E-09	2.800E-09
SKIN(FGR)	5.830E-14	1.150E-10	4.897E-10	4.550E-15-1.000E+00	0.000E+00	0.000E+00
I-134							
GONADS	1.270E-13	1.200E-11	1.202E-11	2.640E-15-1.000E+00	4.250E-12	1.100E-11
BREAST	1.440E-13	1.145E-11	1.147E-11	2.520E-15-1.000E+00	6.170E-12	1.170E-11
LUNGS	1.270E-13	1.100E-11	1.102E-11	2.420E-15-1.000E+00	1.430E-10	1.260E-11
RED MARR	1.250E-13	1.127E-11	1.129E-11	2.480E-15-1.000E+00	6.080E-12	1.090E-11

```
BONE SUR    1.960E-13 1.568E-11 1.571E-11 3.450E-15-1.000E+00 5.310E-12 9.320E-12
THYROID     1.300E-13 1.127E-11 1.129E-11 2.480E-15-1.000E+00 2.880E-10 6.210E-10
REMAINDER   1.220E-13 1.091E-11 1.093E-11 2.400E-15-1.000E+00 2.270E-11 1.340E-10
EFFECTIVE   1.300E-13 1.150E-11 1.152E-11 2.530E-15-1.000E+00 3.550E-11 6.660E-11
SKIN(FGR)   1.870E-13 4.477E-11 4.485E-11 9.850E-15-1.000E+00 0.000E+00 0.000E+00
I-135
GONADS      8.078E-14 3.113E-11 5.489E-11 1.599E-15-1.000E+00 1.700E-11 3.610E-11
BREAST      9.143E-14 2.971E-11 5.240E-11 1.526E-15-1.000E+00 2.340E-11 3.850E-11
LUNGS       8.145E-14 2.886E-11 5.089E-11 1.482E-15-1.000E+00 4.410E-10 3.750E-11
RED MARR    8.054E-14 2.965E-11 5.228E-11 1.523E-15-1.000E+00 2.240E-11 3.650E-11
BONE SUR    1.184E-13 3.983E-11 7.024E-11 2.046E-15-1.000E+00 2.010E-11 3.360E-11
THYROID     8.324E-14 2.852E-11 5.030E-11 1.465E-15-1.000E+00 8.460E-09 1.790E-08
REMAINDER   7.861E-14 2.883E-11 5.084E-11 1.481E-15-1.000E+00 4.700E-11 1.540E-10
EFFECTIVE   8.294E-14 2.989E-11 5.271E-11 1.535E-15-1.000E+00 3.320E-10 6.080E-10
SKIN(FGR)   1.156E-13 9.826E-11 1.733E-10 5.047E-15-1.000E+00 0.000E+00 0.000E+00
Xe-131m
GONADS      4.570E-16 7.872E-13 1.371E-11 2.760E-17-1.000E+00 0.000E+00 0.000E+00
BREAST      6.020E-16 8.471E-13 1.475E-11 2.970E-17-1.000E+00 0.000E+00 0.000E+00
LUNGS       2.670E-16 3.565E-13 6.209E-12 1.250E-17-1.000E+00 0.000E+00 0.000E+00
RED MARR    2.270E-16 2.792E-13 4.863E-12 9.790E-18-1.000E+00 0.000E+00 0.000E+00
BONE SUR    1.060E-15 1.677E-12 2.920E-11 5.880E-17-1.000E+00 0.000E+00 0.000E+00
THYROID     3.910E-16 5.220E-13 9.089E-12 1.830E-17-1.000E+00 0.000E+00 0.000E+00
REMAINDER   2.710E-16 3.993E-13 6.954E-12 1.400E-17-1.000E+00 0.000E+00 0.000E+00
EFFECTIVE   3.890E-16 5.876E-13 1.023E-11 2.060E-17-1.000E+00 0.000E+00 0.000E+00
SKIN(FGR)   4.820E-15 1.266E-12 2.205E-11 4.440E-17-1.000E+00 0.000E+00 0.000E+00
Xe-133m
GONADS      1.420E-15 1.337E-12 1.188E-11 4.890E-17-1.000E+00 0.000E+00 0.000E+00
BREAST      1.700E-15 1.383E-12 1.230E-11 5.060E-17-1.000E+00 0.000E+00 0.000E+00
LUNGS       1.190E-15 8.609E-13 7.656E-12 3.150E-17-1.000E+00 0.000E+00 0.000E+00
RED MARR    1.100E-15 7.844E-13 6.975E-12 2.870E-17-1.000E+00 0.000E+00 0.000E+00
BONE SUR    3.230E-15 2.599E-12 2.311E-11 9.510E-17-1.000E+00 0.000E+00 0.000E+00
THYROID     1.360E-15 1.028E-12 9.138E-12 3.760E-17-1.000E+00 0.000E+00 0.000E+00
REMAINDER   1.150E-15 8.855E-13 7.874E-12 3.240E-17-1.000E+00 0.000E+00 0.000E+00
EFFECTIVE   1.370E-15 1.112E-12 9.892E-12 4.070E-17-1.000E+00 0.000E+00 0.000E+00
SKIN(FGR)   1.040E-14 1.894E-12 1.684E-11 6.930E-17-1.000E+00 0.000E+00 0.000E+00
Xe-133
GONADS      1.610E-15 1.465E-12 2.052E-11 5.200E-17-1.000E+00 0.000E+00 0.000E+00
BREAST      1.960E-15 1.505E-12 2.107E-11 5.340E-17-1.000E+00 0.000E+00 0.000E+00
LUNGS       1.320E-15 1.045E-12 1.464E-11 3.710E-17-1.000E+00 0.000E+00 0.000E+00
RED MARR    1.070E-15 8.791E-13 1.231E-11 3.120E-17-1.000E+00 0.000E+00 0.000E+00
BONE SUR    5.130E-15 4.254E-12 5.958E-11 1.510E-16-1.000E+00 0.000E+00 0.000E+00
THYROID     1.510E-15 1.181E-12 1.653E-11 4.190E-17-1.000E+00 0.000E+00 0.000E+00
REMAINDER   1.240E-15 1.042E-12 1.460E-11 3.700E-17-1.000E+00 0.000E+00 0.000E+00
EFFECTIVE   1.560E-15 1.299E-12 1.819E-11 4.610E-17-1.000E+00 0.000E+00 0.000E+00
SKIN(FGR)   4.970E-15 1.953E-12 2.734E-11 6.930E-17-1.000E+00 0.000E+00 0.000E+00
Xe-135m
GONADS      2.000E-14 5.929E-13 5.929E-13 4.480E-16-1.000E+00 0.000E+00 0.000E+00
BREAST      2.290E-14 5.691E-13 5.691E-13 4.300E-16-1.000E+00 0.000E+00 0.000E+00
LUNGS       1.980E-14 5.347E-13 5.347E-13 4.040E-16-1.000E+00 0.000E+00 0.000E+00
RED MARR    1.910E-14 5.400E-13 5.400E-13 4.080E-16-1.000E+00 0.000E+00 0.000E+00
BONE SUR    3.500E-14 8.246E-13 8.246E-13 6.230E-16-1.000E+00 0.000E+00 0.000E+00
THYROID     2.040E-14 5.612E-13 5.612E-13 4.240E-16-1.000E+00 0.000E+00 0.000E+00
REMAINDER   1.890E-14 5.241E-13 5.241E-13 3.960E-16-1.000E+00 0.000E+00 0.000E+00
EFFECTIVE   2.040E-14 5.612E-13 5.612E-13 4.240E-16-1.000E+00 0.000E+00 0.000E+00
SKIN(FGR)   2.970E-14 1.866E-12 1.866E-12 1.410E-15-1.000E+00 0.000E+00 0.000E+00
Xe-135
GONADS      1.170E-14 5.455E-12 1.194E-11 2.530E-16-1.000E+00 0.000E+00 0.000E+00
BREAST      1.330E-14 5.325E-12 1.166E-11 2.470E-16-1.000E+00 0.000E+00 0.000E+00
LUNGS       1.130E-14 4.959E-12 1.086E-11 2.300E-16-1.000E+00 0.000E+00 0.000E+00
RED MARR    1.070E-14 4.959E-12 1.086E-11 2.300E-16-1.000E+00 0.000E+00 0.000E+00
BONE SUR    2.570E-14 9.120E-12 1.997E-11 4.230E-16-1.000E+00 0.000E+00 0.000E+00
THYROID     1.180E-14 5.023E-12 1.100E-11 2.330E-16-1.000E+00 0.000E+00 0.000E+00
REMAINDER   1.080E-14 4.829E-12 1.058E-11 2.240E-16-1.000E+00 0.000E+00 0.000E+00
EFFECTIVE   1.190E-14 5.217E-12 1.142E-11 2.420E-16-1.000E+00 0.000E+00 0.000E+00
SKIN(FGR)   3.120E-14 4.506E-11 9.867E-11 2.090E-15-1.000E+00 0.000E+00 0.000E+00
Kr-83m
GONADS      1.710E-18 5.572E-15 5.855E-15 6.160E-19-1.000E+00 0.000E+00 0.000E+00
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BREAST       5.050E-18 9.498E-15 9.980E-15 1.050E-18-1.000E+00 0.000E+00 0.000E+00
LUNGS        1.640E-19 1.266E-16 1.331E-16 1.400E-20-1.000E+00 0.000E+00 0.000E+00
RED MARR     3.830E-19 5.617E-16 5.902E-16 6.210E-20-1.000E+00 0.000E+00 0.000E+00
BONE SUR     2.250E-18 3.437E-15 3.612E-15 3.800E-19-1.000E+00 0.000E+00 0.000E+00
THYROID      6.430E-19 7.698E-16 8.088E-16 8.510E-20-1.000E+00 0.000E+00 0.000E+00
REMAINDER    5.300E-19 1.393E-15 1.464E-15 1.540E-19-1.000E+00 0.000E+00 0.000E+00
EFFECTIVE    1.500E-18 3.437E-15 3.612E-15 3.800E-19-1.000E+00 0.000E+00 0.000E+00
SKIN(FGR)    3.560E-17 1.167E-13 1.226E-13 1.290E-17-1.000E+00 0.000E+00 0.000E+00
Kr-85m
GONADS       7.310E-15 2.594E-12 3.653E-12 1.570E-16-1.000E+00 0.000E+00 0.000E+00
BREAST       8.410E-15 2.527E-12 3.560E-12 1.530E-16-1.000E+00 0.000E+00 0.000E+00
LUNGS        7.040E-15 2.379E-12 3.351E-12 1.440E-16-1.000E+00 0.000E+00 0.000E+00
RED MARR     6.430E-15 2.346E-12 3.304E-12 1.420E-16-1.000E+00 0.000E+00 0.000E+00
BONE SUR     1.880E-14 5.286E-12 7.446E-12 3.200E-16-1.000E+00 0.000E+00 0.000E+00
THYROID      7.330E-15 2.395E-12 3.374E-12 1.450E-16-1.000E+00 0.000E+00 0.000E+00
REMAINDER    6.640E-15 2.313E-12 3.257E-12 1.400E-16-1.000E+00 0.000E+00 0.000E+00
EFFECTIVE    7.480E-15 2.511E-12 3.537E-12 1.520E-16-1.000E+00 0.000E+00 0.000E+00
SKIN(FGR)    2.240E-14 2.247E-11 3.164E-11 1.360E-15-1.000E+00 0.000E+00 0.000E+00
Kr-87
GONADS       4.000E-14 4.962E-12 5.026E-12 7.610E-16-1.000E+00 0.000E+00 0.000E+00
BREAST       4.500E-14 4.740E-12 4.802E-12 7.270E-16-1.000E+00 0.000E+00 0.000E+00
LUNGS        4.040E-14 4.603E-12 4.663E-12 7.060E-16-1.000E+00 0.000E+00 0.000E+00
RED MARR     4.000E-14 4.708E-12 4.769E-12 7.220E-16-1.000E+00 0.000E+00 0.000E+00
BONE SUR     6.020E-14 6.514E-12 6.598E-12 9.990E-16-1.000E+00 0.000E+00 0.000E+00
THYROID      4.130E-14 4.473E-12 4.531E-12 6.860E-16-1.000E+00 0.000E+00 0.000E+00
REMAINDER    3.910E-14 4.590E-12 4.650E-12 7.040E-16-1.000E+00 0.000E+00 0.000E+00
EFFECTIVE    4.120E-14 4.773E-12 4.835E-12 7.320E-16-1.000E+00 0.000E+00 0.000E+00
SKIN(FGR)    1.370E-13 8.802E-11 8.916E-11 1.350E-14-1.000E+00 0.000E+00 0.000E+00
Kr-88
GONADS       9.900E-14 2.278E-11 2.655E-11 1.800E-15-1.000E+00 0.000E+00 0.000E+00
BREAST       1.110E-13 2.177E-11 2.537E-11 1.720E-15-1.000E+00 0.000E+00 0.000E+00
LUNGS        1.010E-13 2.139E-11 2.493E-11 1.690E-15-1.000E+00 0.000E+00 0.000E+00
RED MARR     1.000E-13 2.190E-11 2.552E-11 1.730E-15-1.000E+00 0.000E+00 0.000E+00
BONE SUR     1.390E-13 2.886E-11 3.363E-11 2.280E-15-1.000E+00 0.000E+00 0.000E+00
THYROID      1.030E-13 2.012E-11 2.345E-11 1.590E-15-1.000E+00 0.000E+00 0.000E+00
REMAINDER    9.790E-14 2.139E-11 2.493E-11 1.690E-15-1.000E+00 0.000E+00 0.000E+00
EFFECTIVE    1.020E-13 2.202E-11 2.567E-11 1.740E-15-1.000E+00 0.000E+00 0.000E+00
SKIN(FGR)    1.350E-13 5.607E-11 6.534E-11 4.430E-15-1.000E+00 0.000E+00 0.000E+00
```

Note: These values are stored as file "TID.INP." The corresponding file that contains the atomic weights and half-lives for these isotopes is "TID.NIF."

Table 1.4.3.3-2 Dose Conversion Factors for NUREG-1465 Nuclides

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FGRDCF 10/24/95   03:24:50    beta-test version 1.10, minor Fortran fixes 5/4/95
Implicit daughter half-lives (m) less than  90 and less than 0.100 of parent
          9 ORGANS DEFINED IN THIS FILE:
GONADS
BREAST
LUNGS
RED MARR
BONE SUR
THYROID
REMAINDER
EFFECTIVE
SKIN(FGR)
          60 NUCLIDES DEFINED IN THIS FILE:
Co-58      Y
Co-60      Y
Kr-85
Kr-85m
Kr-87
Kr-88
Rb-86      D
Sr-89      Y
Sr-90      Y
Sr-91      Y       Including:Y-91m
Sr-92      Y
Y-90       Y
Y-91       Y
Y-92       Y
Y-93       Y
Zr-95      D
Zr-97      Y       Including:Nb-97m , Including:Nb-97
Nb-95      Y
Mo-99      Y
Tc-99m     D
Ru-103     Y       Including:Rh-103m
Ru-105     Y
Ru-106     Y       Including:Rh-106
Rh-105     Y
Sb-127     W
Sb-129     W
Te-127     W
Te-127m    W
Te-129     W
Te-129m    W       Including:Te-129
Te-131m    W       Including:Te-131
Te-132     W
I-131      D
I-132      D
I-133      D
I-134      D
I-135      D       Including:Xe-135m
Xe-133
Xe-135
Cs-134     D
Cs-136     D
Cs-137     D       Including:Ba-137m
Ba-139     D
Ba-140     D
La-140     W
La-141     D
La-142     D
Ce-141     Y
Ce-143     Y
Ce-144     Y       Including:Pr-144m, Including:Pr-144
Pr-143     Y
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Nd-147      Y
Np-239      W
Pu-238      Y
Pu-239      Y
Pu-240      Y
Pu-241      Y
Am-241      W
Cm-242      W
Cm-244      W
```

	CLOUDSHINE	GROUND SHINE 8HR	GROUND SHINE 7DAY	GROUND SHINE RATE	INHALED ACUTE	INHALED CHRONIC	INGESTION
Co-58							
GONADS	4.660E-14	2.867E-11	5.828E-10	9.970E-16	1.000E+00	6.170E-10	1.040E-09
BREAST	5.300E-14	2.737E-11	5.565E-10	9.520E-16	1.000E+00	9.370E-10	1.790E-10
LUNGS	4.640E-14	2.617E-11	5.319E-10	9.100E-16	1.000E+00	1.600E-08	8.530E-11
RED MARR	4.530E-14	2.671E-11	5.430E-10	9.290E-16	1.000E+00	9.230E-10	2.600E-10
BONE SUR	7.410E-14	3.795E-11	7.716E-10	1.320E-15	1.000E+00	6.930E-10	1.250E-10
THYROID	4.770E-14	2.720E-11	5.530E-10	9.460E-16	1.000E+00	8.720E-10	6.310E-11
REMAINDER	4.440E-14	2.585E-11	5.255E-10	8.990E-16	1.000E+00	1.890E-09	1.580E-09
EFFECTIVE	4.760E-14	2.732E-11	5.553E-10	9.500E-16	1.000E+00	2.940E-09	8.090E-10
SKIN(FGR)	5.580E-14	3.278E-11	6.664E-10	1.140E-15	1.000E+00	0.000E+00	0.000E+00
Co-60							
GONADS	1.230E-13	7.056E-11	1.480E-09	2.450E-15	1.000E+00	4.760E-09	3.190E-09
BREAST	1.390E-13	6.739E-11	1.413E-09	2.340E-15	1.000E+00	1.840E-08	1.100E-09
LUNGS	1.240E-13	6.537E-11	1.371E-09	2.270E-15	1.000E+00	3.450E-07	8.770E-10
RED MARR	1.230E-13	6.710E-11	1.407E-09	2.330E-15	1.000E+00	1.720E-08	1.320E-09
BONE SUR	1.780E-13	8.956E-11	1.879E-09	3.110E-15	1.000E+00	1.350E-08	9.390E-10
THYROID	1.270E-13	6.480E-11	1.359E-09	2.250E-15	1.000E+00	1.620E-08	7.880E-10
REMAINDER	1.200E-13	6.508E-11	1.365E-09	2.260E-15	1.000E+00	3.600E-08	4.970E-09
EFFECTIVE	1.260E-13	6.768E-11	1.419E-09	2.350E-15	1.000E+00	5.910E-08	2.770E-09
SKIN(FGR)	1.450E-13	7.948E-11	1.667E-09	2.760E-15	1.000E+00	0.000E+00	0.000E+00
Kr-85							
GONADS	1.170E-16	8.121E-14	1.704E-12	2.820E-18	1.000E+00	0.000E+00	0.000E+00
BREAST	1.340E-16	7.891E-14	1.656E-12	2.740E-18	1.000E+00	0.000E+00	0.000E+00
LUNGS	1.140E-16	7.056E-14	1.481E-12	2.450E-18	1.000E+00	0.000E+00	0.000E+00
RED MARR	1.090E-16	6.998E-14	1.469E-12	2.430E-18	1.000E+00	0.000E+00	0.000E+00
BONE SUR	2.200E-16	1.287E-13	2.702E-12	4.470E-18	1.000E+00	0.000E+00	0.000E+00
THYROID	1.180E-16	7.459E-14	1.565E-12	2.590E-18	1.000E+00	0.000E+00	0.000E+00
REMAINDER	1.090E-16	6.941E-14	1.457E-12	2.410E-18	1.000E+00	0.000E+00	0.000E+00
EFFECTIVE	1.190E-16	7.603E-14	1.596E-12	2.640E-18	1.000E+00	0.000E+00	0.000E+00
SKIN(FGR)	1.320E-14	2.304E-11	4.835E-10	8.000E-16	1.000E+00	0.000E+00	0.000E+00
Kr-85m							
GONADS	7.310E-15	2.594E-12	3.653E-12	1.570E-16	1.000E+00	0.000E+00	0.000E+00
BREAST	8.410E-15	2.527E-12	3.560E-12	1.530E-16	1.000E+00	0.000E+00	0.000E+00
LUNGS	7.040E-15	2.379E-12	3.351E-12	1.440E-16	1.000E+00	0.000E+00	0.000E+00
RED MARR	6.430E-15	2.346E-12	3.304E-12	1.420E-16	1.000E+00	0.000E+00	0.000E+00
BONE SUR	1.880E-14	5.286E-12	7.446E-12	3.200E-16	1.000E+00	0.000E+00	0.000E+00
THYROID	7.330E-15	2.395E-12	3.374E-12	1.450E-16	1.000E+00	0.000E+00	0.000E+00
REMAINDER	6.640E-15	2.313E-12	3.257E-12	1.400E-16	1.000E+00	0.000E+00	0.000E+00
EFFECTIVE	7.480E-15	2.511E-12	3.537E-12	1.520E-16	1.000E+00	0.000E+00	0.000E+00
SKIN(FGR)	2.240E-14	2.247E-11	3.164E-11	1.360E-15	1.000E+00	0.000E+00	0.000E+00
Kr-87							
GONADS	4.000E-14	4.962E-12	5.026E-12	7.610E-16	1.000E+00	0.000E+00	0.000E+00
BREAST	4.500E-14	4.740E-12	4.802E-12	7.270E-16	1.000E+00	0.000E+00	0.000E+00
LUNGS	4.040E-14	4.603E-12	4.663E-12	7.060E-16	1.000E+00	0.000E+00	0.000E+00
RED MARR	4.000E-14	4.708E-12	4.769E-12	7.220E-16	1.000E+00	0.000E+00	0.000E+00
BONE SUR	6.020E-14	6.514E-12	6.598E-12	9.990E-16	1.000E+00	0.000E+00	0.000E+00
THYROID	4.130E-14	4.473E-12	4.531E-12	6.860E-16	1.000E+00	0.000E+00	0.000E+00
REMAINDER	3.910E-14	4.590E-12	4.650E-12	7.040E-16	1.000E+00	0.000E+00	0.000E+00
EFFECTIVE	4.120E-14	4.773E-12	4.835E-12	7.320E-16	1.000E+00	0.000E+00	0.000E+00
SKIN(FGR)	1.370E-13	8.802E-11	8.916E-11	1.350E-14	1.000E+00	0.000E+00	0.000E+00
Kr-88							
GONADS	9.900E-14	2.278E-11	2.655E-11	1.800E-15	1.000E+00	0.000E+00	0.000E+00
BREAST	1.110E-13	2.177E-11	2.537E-11	1.720E-15	1.000E+00	0.000E+00	0.000E+00
LUNGS	1.010E-13	2.139E-11	2.493E-11	1.690E-15	1.000E+00	0.000E+00	0.000E+00
RED MARR	1.000E-13	2.190E-11	2.552E-11	1.730E-15	1.000E+00	0.000E+00	0.000E+00
BONE SUR	1.390E-13	2.886E-11	3.363E-11	2.280E-15	1.000E+00	0.000E+00	0.000E+00

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THYROID     1.030E-13 2.012E-11 2.345E-11 1.590E-15-1.000E+00 0.000E+00 0.000E+00
REMAINDER   9.790E-14 2.139E-11 2.493E-11 1.690E-15-1.000E+00 0.000E+00 0.000E+00
EFFECTIVE   1.020E-13 2.202E-11 2.567E-11 1.740E-15-1.000E+00 0.000E+00 0.000E+00
SKIN(FGR)   1.350E-13 5.607E-11 6.534E-11 4.430E-15-1.000E+00 0.000E+00 0.000E+00
Rb-86
GONADS      4.710E-15 2.788E-12 5.187E-11 9.740E-17-1.000E+00 1.340E-09 2.150E-09
BREAST      5.340E-15 2.662E-12 4.953E-11 9.300E-17-1.000E+00 1.330E-09 2.140E-09
LUNGS       4.710E-15 2.553E-12 4.750E-11 8.920E-17-1.000E+00 3.300E-09 2.140E-09
RED MARR    4.640E-15 2.619E-12 4.873E-11 9.150E-17-1.000E+00 2.320E-09 3.720E-09
BONE SUR    7.050E-15 3.635E-12 6.764E-11 1.270E-16-1.000E+00 4.270E-09 6.860E-09
THYROID     4.840E-15 2.599E-12 4.836E-11 9.080E-17-1.000E+00 1.330E-09 2.140E-09
REMAINDER   4.520E-15 2.542E-12 4.729E-11 8.880E-17-1.000E+00 1.380E-09 2.330E-09
EFFECTIVE   4.810E-15 2.665E-12 4.958E-11 9.310E-17-1.000E+00 1.790E-09 2.530E-09
SKIN(FGR)   4.850E-14 2.210E-10 4.111E-09 7.720E-15-1.000E+00 0.000E+00 0.000E+00
Sr-89
GONADS      7.730E-17 7.155E-14 1.436E-12 2.490E-18-1.000E+00 7.950E-12 8.050E-12
BREAST      9.080E-17 7.212E-14 1.447E-12 2.510E-18-1.000E+00 7.960E-12 7.980E-12
LUNGS       7.080E-17 5.689E-14 1.142E-12 1.980E-18-1.000E+00 8.350E-08 7.970E-12
RED MARR    6.390E-17 5.345E-14 1.073E-12 1.860E-18-1.000E+00 1.070E-10 1.080E-10
BONE SUR    1.940E-16 1.560E-13 3.131E-12 5.430E-18-1.000E+00 1.590E-10 1.610E-10
THYROID     7.600E-17 6.063E-14 1.217E-12 2.110E-18-1.000E+00 7.960E-12 7.970E-12
REMAINDER   6.710E-17 5.603E-14 1.124E-12 1.950E-18-1.000E+00 3.970E-09 8.250E-09
EFFECTIVE   7.730E-17 6.523E-14 1.309E-12 2.270E-18-1.000E+00 1.120E-08 2.500E-09
SKIN(FGR)   3.690E-14 1.914E-10 3.841E-09 6.660E-15-1.000E+00 0.000E+00 0.000E+00
Sr-90
GONADS      7.780E-18 9.590E-15 2.014E-13 3.330E-19-1.000E+00 2.690E-10 5.040E-11
BREAST      9.490E-18 1.008E-14 2.116E-13 3.500E-19-1.000E+00 2.690E-10 5.040E-11
LUNGS       6.440E-18 6.307E-15 1.324E-13 2.190E-19-1.000E+00 2.860E-06 5.040E-11
RED MARR    5.440E-18 5.558E-15 1.167E-13 1.930E-19-1.000E+00 3.280E-08 6.450E-09
BONE SUR    2.280E-17 2.393E-14 5.025E-13 8.310E-19-1.000E+00 7.090E-08 1.390E-08
THYROID     7.330E-18 7.171E-15 1.506E-13 2.490E-19-1.000E+00 2.690E-10 5.040E-11
REMAINDER   6.110E-18 6.422E-15 1.348E-13 2.230E-19-1.000E+00 5.730E-09 6.700E-09
EFFECTIVE   7.530E-18 8.179E-15 1.717E-13 2.840E-19-1.000E+00 3.510E-07 3.230E-09
SKIN(FGR)   9.200E-15 4.032E-12 8.465E-11 1.400E-16-1.000E+00 0.000E+00 0.000E+00
Sr-91
GONADS      4.819E-14 2.155E-11 5.062E-11 1.026E-15-1.000E+00 5.669E-11 2.520E-10
BREAST      5.477E-14 2.059E-11 4.838E-11 9.806E-16-1.000E+00 1.775E-11 3.676E-11
LUNGS       4.803E-14 1.970E-11 4.626E-11 9.376E-16-1.000E+00 2.170E-09 1.055E-11
RED MARR    4.691E-14 2.011E-11 4.722E-11 9.570E-16-1.000E+00 2.275E-11 5.659E-11
BONE SUR    7.674E-14 2.852E-11 6.709E-11 1.360E-15-1.000E+00 1.306E-11 2.070E-11
THYROID     4.938E-14 2.035E-11 4.782E-11 9.693E-16-1.000E+00 9.930E-12 1.968E-12
REMAINDER   4.610E-14 1.948E-11 4.573E-11 9.268E-16-1.000E+00 5.802E-10 2.557E-09
EFFECTIVE   4.924E-14 2.057E-11 4.832E-11 9.793E-16-1.000E+00 4.547E-10 8.455E-10
SKIN(FGR)   9.938E-14 1.748E-10 3.987E-10 8.080E-15-1.000E+00 0.000E+00 0.000E+00
Sr-92
GONADS      6.610E-14 1.593E-11 1.830E-11 1.300E-15-1.000E+00 1.020E-11 8.180E-11
BREAST      7.480E-14 1.520E-11 1.745E-11 1.240E-15-1.000E+00 6.490E-12 1.700E-11
LUNGS       6.670E-14 1.483E-11 1.703E-11 1.210E-15-1.000E+00 1.050E-09 7.220E-12
RED MARR    6.620E-14 1.520E-11 1.745E-11 1.240E-15-1.000E+00 6.980E-12 2.290E-11
BONE SUR    9.490E-14 2.010E-11 2.308E-11 1.640E-15-1.000E+00 4.360E-12 8.490E-12
THYROID     6.820E-14 1.446E-11 1.661E-11 1.180E-15-1.000E+00 3.920E-12 1.300E-12
REMAINDER   6.450E-14 1.471E-11 1.689E-11 1.200E-15-1.000E+00 2.900E-10 1.720E-09
EFFECTIVE   6.790E-14 1.532E-11 1.759E-11 1.250E-15-1.000E+00 2.180E-10 5.430E-10
SKIN(FGR)   8.560E-14 2.280E-11 2.618E-11 1.860E-15-1.000E+00 0.000E+00 0.000E+00
Y-90
GONADS      1.890E-16 1.586E-13 1.601E-12 5.750E-18-1.000E+00 5.170E-13 1.430E-14
BREAST      2.200E-16 1.578E-13 1.593E-12 5.720E-18-1.000E+00 5.170E-13 1.270E-14
LUNGS       1.770E-16 1.313E-13 1.326E-12 4.760E-18-1.000E+00 9.310E-09 1.260E-14
RED MARR    1.620E-16 1.261E-13 1.273E-12 4.570E-18-1.000E+00 1.520E-11 3.700E-13
BONE SUR    4.440E-16 3.228E-13 3.259E-12 1.170E-17-1.000E+00 1.510E-11 3.670E-13
THYROID     1.870E-16 1.385E-13 1.398E-12 5.020E-18-1.000E+00 5.170E-13 1.260E-14
REMAINDER   1.680E-16 1.291E-13 1.303E-12 4.680E-18-1.000E+00 3.870E-09 9.680E-09
EFFECTIVE   1.900E-16 1.468E-13 1.482E-12 5.320E-18-1.000E+00 2.280E-09 2.910E-09
SKIN(FGR)   6.240E-14 2.897E-10 2.924E-09 1.050E-14-1.000E+00 0.000E+00 0.000E+00
Y-91
GONADS      2.560E-16 1.756E-13 3.546E-12 6.110E-18-1.000E+00 8.200E-12 3.540E-12
BREAST      2.930E-16 1.713E-13 3.459E-12 5.960E-18-1.000E+00 8.920E-12 5.540E-13
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LUNGS       2.500E-16 1.526E-13 3.082E-12 5.310E-18-1.000E+00 9.870E-08 2.020E-13
RED MARR    2.410E-16 1.521E-13 3.070E-12 5.290E-18-1.000E+00 3.190E-10 6.590E-12
BONE SUR    4.560E-16 2.903E-13 5.862E-12 1.010E-17-1.000E+00 3.180E-10 6.130E-12
THYROID     2.600E-16 1.564E-13 3.157E-12 5.440E-18-1.000E+00 8.500E-12 1.290E-13
REMAINDER   2.390E-16 1.509E-13 3.047E-12 5.250E-18-1.000E+00 4.200E-09 8.570E-09
EFFECTIVE   2.600E-16 1.650E-13 3.332E-12 5.740E-18-1.000E+00 1.320E-08 2.570E-09
SKIN(FGR)   3.850E-14 1.989E-10 4.016E-09 6.920E-15-1.000E+00 0.000E+00 0.000E+00
Y-92
GONADS      1.270E-14 3.855E-12 4.872E-12 2.650E-16-1.000E+00 2.610E-12 1.960E-11
BREAST      1.440E-14 3.680E-12 4.652E-12 2.530E-16-1.000E+00 1.500E-12 3.550E-12
LUNGS       1.270E-14 3.535E-12 4.468E-12 2.430E-16-1.000E+00 1.240E-09 1.390E-12
RED MARR    1.250E-14 3.608E-12 4.560E-12 2.480E-16-1.000E+00 2.070E-12 4.910E-12
BONE SUR    1.950E-14 5.091E-12 6.435E-12 3.500E-16-1.000E+00 1.510E-12 1.750E-12
THYROID     1.300E-14 3.579E-12 4.523E-12 2.460E-16-1.000E+00 1.050E-12 1.770E-13
REMAINDER   1.220E-14 3.506E-12 4.431E-12 2.410E-16-1.000E+00 2.030E-10 1.700E-09
EFFECTIVE   1.300E-14 3.680E-12 4.652E-12 2.530E-16-1.000E+00 2.110E-10 5.150E-10
SKIN(FGR)   1.140E-13 2.022E-10 2.556E-10 1.390E-14-1.000E+00 0.000E+00 0.000E+00
Y-93
GONADS      4.670E-15 2.108E-12 4.989E-12 9.510E-17-1.000E+00 5.310E-12 2.200E-11
BREAST      5.300E-15 2.026E-12 4.794E-12 9.140E-17-1.000E+00 1.740E-12 3.130E-12
LUNGS       4.680E-15 1.937E-12 4.585E-12 8.740E-17-1.000E+00 2.520E-09 8.670E-13
RED MARR    4.580E-15 1.972E-12 4.669E-12 8.900E-17-1.000E+00 4.040E-12 4.930E-12
BONE SUR    7.580E-15 2.948E-12 6.977E-12 1.330E-16-1.000E+00 3.140E-12 1.730E-12
THYROID     4.790E-15 1.908E-12 4.516E-12 8.610E-17-1.000E+00 9.260E-13 1.260E-13
REMAINDER   4.510E-15 1.919E-12 4.543E-12 8.660E-17-1.000E+00 9.250E-10 4.090E-09
EFFECTIVE   4.800E-15 2.021E-12 4.784E-12 9.120E-17-1.000E+00 5.820E-10 1.230E-09
SKIN(FGR)   8.500E-14 2.726E-10 6.452E-10 1.230E-14-1.000E+00 0.000E+00 0.000E+00
Zr-95
GONADS      3.530E-14 2.182E-11 4.421E-10 7.590E-16-1.000E+00 1.880E-09 8.160E-10
BREAST      4.010E-14 2.084E-11 4.223E-10 7.250E-16-1.000E+00 1.910E-09 1.050E-10
LUNGS       3.510E-14 1.989E-11 4.030E-10 6.920E-16-1.000E+00 2.170E-09 2.340E-11
RED MARR    3.430E-14 2.030E-11 4.112E-10 7.060E-16-1.000E+00 1.300E-08 2.140E-10
BONE SUR    5.620E-14 2.875E-11 5.824E-10 1.000E-15-1.000E+00 1.030E-07 4.860E-10
THYROID     3.610E-14 2.076E-11 4.205E-10 7.220E-16-1.000E+00 1.440E-09 8.270E-12
REMAINDER   3.360E-14 1.963E-11 3.978E-10 6.830E-16-1.000E+00 2.280E-09 2.530E-09
EFFECTIVE   3.600E-14 2.078E-11 4.211E-10 7.230E-16-1.000E+00 6.390E-09 1.020E-09
SKIN(FGR)   4.500E-14 2.561E-11 5.190E-10 8.910E-16-1.000E+00 0.000E+00 0.000E+00
Zr-97
GONADS      4.331E-14 2.179E-11 7.799E-11 9.253E-16-1.000E+00 1.840E-10 6.228E-10
BREAST      4.928E-14 2.083E-11 7.455E-11 8.846E-16-1.000E+00 4.706E-11 8.137E-11
LUNGS       4.322E-14 1.992E-11 7.127E-11 8.456E-16-1.000E+00 4.108E-09 1.770E-11
RED MARR    4.224E-14 2.034E-11 7.279E-11 8.634E-16-1.000E+00 6.376E-11 1.302E-10
BONE SUR    6.897E-14 2.881E-11 1.031E-10 1.224E-15-1.000E+00 3.504E-11 4.558E-11
THYROID     4.443E-14 2.061E-11 7.377E-11 8.755E-16-1.000E+00 2.315E-11 2.671E-12
REMAINDER   4.139E-14 1.966E-11 7.035E-11 8.345E-16-1.000E+00 2.041E-09 6.990E-09
EFFECTIVE   4.432E-14 2.078E-11 7.438E-11 8.824E-16-1.000E+00 1.171E-09 2.283E-09
SKIN(FGR)   9.835E-14 2.281E-10 8.148E-10 9.587E-15-1.000E+00 0.000E+00 0.000E+00
Nb-95
GONADS      3.660E-14 2.253E-11 4.435E-10 7.850E-16-1.000E+00 4.320E-10 8.050E-10
BREAST      4.160E-14 2.150E-11 4.231E-10 7.490E-16-1.000E+00 4.070E-10 1.070E-10
LUNGS       3.650E-14 2.055E-11 4.045E-10 7.160E-16-1.000E+00 8.320E-09 2.740E-11
RED MARR    3.560E-14 2.101E-11 4.135E-10 7.320E-16-1.000E+00 4.420E-10 1.990E-10
BONE SUR    5.790E-14 2.957E-11 5.819E-10 1.030E-15-1.000E+00 5.130E-10 2.940E-10
THYROID     3.750E-14 2.144E-11 4.220E-10 7.470E-16-1.000E+00 3.580E-10 1.180E-11
REMAINDER   3.490E-14 2.032E-11 4.000E-10 7.080E-16-1.000E+00 1.070E-09 1.470E-09
EFFECTIVE   3.740E-14 2.147E-11 4.226E-10 7.480E-16-1.000E+00 1.570E-09 6.950E-10
SKIN(FGR)   4.300E-14 2.598E-11 5.112E-10 9.050E-16-1.000E+00 0.000E+00 0.000E+00
Mo-99
GONADS      7.130E-15 4.282E-12 4.403E-11 1.550E-16-1.000E+00 9.510E-11 2.180E-10
BREAST      8.130E-15 4.116E-12 4.233E-11 1.490E-16-1.000E+00 2.750E-11 3.430E-11
LUNGS       7.060E-15 3.867E-12 3.977E-11 1.400E-16-1.000E+00 4.290E-09 1.510E-11
RED MARR    6.820E-15 3.923E-12 4.034E-11 1.420E-16-1.000E+00 5.240E-11 8.320E-11
BONE SUR    1.240E-14 6.105E-12 6.278E-11 2.210E-16-1.000E+00 4.130E-11 6.320E-11
THYROID     7.270E-15 4.033E-12 4.147E-11 1.460E-16-1.000E+00 1.520E-11 1.030E-11
REMAINDER   6.740E-15 3.812E-12 3.920E-11 1.380E-16-1.000E+00 1.740E-09 4.280E-09
EFFECTIVE   7.280E-15 4.061E-12 4.176E-11 1.470E-16-1.000E+00 1.070E-09 1.360E-09
SKIN(FGR)   3.140E-14 1.039E-10 1.068E-09 3.760E-15-1.000E+00 0.000E+00 0.000E+00
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Tc-99m
GONADS      5.750E-15 2.334E-12 3.877E-12 1.240E-16-1.000E+00 2.770E-12 9.750E-12
BREAST      6.650E-15 2.258E-12 3.752E-12 1.200E-16-1.000E+00 2.150E-12 3.570E-12
LUNGS       5.490E-15 2.127E-12 3.533E-12 1.130E-16-1.000E+00 2.280E-11 3.140E-12
RED MARR    4.910E-15 2.070E-12 3.439E-12 1.100E-16-1.000E+00 3.360E-12 6.290E-12
BONE SUR    1.630E-14 5.383E-12 8.942E-12 2.860E-16-1.000E+00 2.620E-12 4.060E-12
THYROID     5.750E-15 2.145E-12 3.564E-12 1.140E-16-1.000E+00 5.010E-11 8.460E-11
REMAINDER   5.150E-15 2.070E-12 3.439E-12 1.100E-16-1.000E+00 1.020E-11 3.340E-11
EFFECTIVE   5.890E-15 2.277E-12 3.783E-12 1.210E-16-1.000E+00 8.800E-12 1.680E-11
SKIN(FGR)   7.140E-15 2.710E-12 4.502E-12 1.440E-16-1.000E+00 0.000E+00 0.000E+00
Ru-103
GONADS      2.191E-14 1.404E-11 2.783E-10 4.892E-16-1.000E+00 3.070E-10 5.720E-10
BREAST      2.512E-14 1.350E-11 2.677E-10 4.705E-16-1.000E+00 3.110E-10 1.200E-10
LUNGS       2.180E-14 1.273E-11 2.522E-10 4.432E-16-1.000E+00 1.561E-08 7.310E-11
RED MARR    2.100E-14 1.287E-11 2.551E-10 4.483E-16-1.000E+00 3.190E-10 1.660E-10
BONE SUR    3.892E-14 1.958E-11 3.882E-10 6.823E-16-1.000E+00 2.370E-10 9.631E-11
THYROID     2.241E-14 1.331E-11 2.639E-10 4.638E-16-1.000E+00 2.570E-10 6.250E-11
REMAINDER   2.080E-14 1.248E-11 2.472E-10 4.346E-16-1.000E+00 1.250E-09 2.110E-09
EFFECTIVE   2.251E-14 1.332E-11 2.641E-10 4.642E-16-1.000E+00 2.421E-09 8.271E-10
SKIN(FGR)   2.774E-14 1.785E-11 3.543E-10 6.229E-16-1.000E+00 0.000E+00 0.000E+00
Ru-105
GONADS      3.720E-14 1.327E-11 1.861E-11 8.070E-16-1.000E+00 1.590E-11 9.670E-11
BREAST      4.240E-14 1.271E-11 1.783E-11 7.730E-16-1.000E+00 6.610E-12 1.590E-11
LUNGS       3.700E-14 1.210E-11 1.697E-11 7.360E-16-1.000E+00 5.730E-10 6.210E-12
RED MARR    3.590E-14 1.230E-11 1.725E-11 7.480E-16-1.000E+00 7.700E-12 2.350E-11
BONE SUR    6.280E-14 1.809E-11 2.537E-11 1.100E-15-1.000E+00 4.620E-12 8.890E-12
THYROID     3.800E-14 1.260E-11 1.766E-11 7.660E-16-1.000E+00 4.150E-12 1.820E-12
REMAINDER   3.540E-14 1.189E-11 1.667E-11 7.230E-16-1.000E+00 1.610E-10 8.540E-10
EFFECTIVE   3.810E-14 1.265E-11 1.773E-11 7.690E-16-1.000E+00 1.230E-10 2.870E-10
SKIN(FGR)   6.730E-14 7.368E-11 1.033E-10 4.480E-15-1.000E+00 0.000E+00 0.000E+00
Ru-106
GONADS      1.010E-14 6.411E-12 1.340E-10 2.230E-16-1.000E+00 1.300E-09 1.640E-09
BREAST      1.160E-14 6.152E-12 1.286E-10 2.140E-16-1.000E+00 1.780E-09 1.440E-09
LUNGS       1.010E-14 5.836E-12 1.220E-10 2.030E-16-1.000E+00 1.040E-06 1.420E-09
RED MARR    9.750E-15 5.893E-12 1.232E-10 2.050E-16-1.000E+00 1.760E-09 1.460E-09
BONE SUR    1.720E-14 8.883E-12 1.856E-10 3.090E-16-1.000E+00 1.610E-09 1.430E-09
THYROID     1.030E-14 6.066E-12 1.268E-10 2.110E-16-1.000E+00 1.720E-09 1.410E-09
REMAINDER   9.630E-15 5.721E-12 1.196E-10 1.990E-16-1.000E+00 1.200E-08 2.110E-08
EFFECTIVE   1.040E-14 6.095E-12 1.274E-10 2.120E-16-1.000E+00 1.290E-07 7.400E-09
SKIN(FGR)   1.090E-13 4.082E-10 8.531E-09 1.420E-14-1.000E+00 0.000E+00 0.000E+00
Rh-105
GONADS      3.640E-15 2.127E-12 1.411E-11 7.980E-17-1.000E+00 2.110E-11 5.800E-11
BREAST      4.160E-15 2.063E-12 1.369E-11 7.740E-17-1.000E+00 5.610E-12 8.970E-12
LUNGS       3.570E-15 1.935E-12 1.284E-11 7.260E-17-1.000E+00 9.580E-10 3.860E-12
RED MARR    3.380E-15 1.946E-12 1.291E-11 7.300E-17-1.000E+00 7.770E-12 1.470E-11
BONE SUR    7.530E-15 3.332E-12 2.210E-11 1.250E-16-1.000E+00 4.460E-12 6.750E-12
THYROID     3.680E-15 1.983E-12 1.316E-11 7.440E-17-1.000E+00 2.880E-12 2.910E-12
REMAINDER   3.390E-15 1.885E-12 1.250E-11 7.070E-17-1.000E+00 4.530E-10 1.270E-09
EFFECTIVE   3.720E-15 2.031E-12 1.347E-11 7.620E-17-1.000E+00 2.580E-10 3.990E-10
SKIN(FGR)   1.070E-14 4.691E-12 3.112E-11 1.760E-16-1.000E+00 0.000E+00 0.000E+00
Sb-127
GONADS      3.260E-14 1.985E-11 2.441E-10 7.100E-16-1.000E+00 2.520E-10 6.140E-10
BREAST      3.720E-14 1.904E-11 2.341E-10 6.810E-16-1.000E+00 9.120E-11 7.600E-11
LUNGS       3.240E-14 1.809E-11 2.224E-10 6.470E-16-1.000E+00 6.940E-09 1.570E-11
RED MARR    3.140E-14 1.834E-11 2.255E-10 6.560E-16-1.000E+00 1.610E-10 1.330E-10
BONE SUR    5.520E-14 2.720E-11 3.345E-10 9.730E-16-1.000E+00 1.340E-10 5.240E-11
THYROID     3.330E-14 1.884E-11 2.317E-10 6.740E-16-1.000E+00 6.150E-11 4.640E-12
REMAINDER   3.090E-14 1.775E-11 2.183E-10 6.350E-16-1.000E+00 2.330E-09 5.870E-09
EFFECTIVE   3.330E-14 1.890E-11 2.324E-10 6.760E-16-1.000E+00 1.630E-09 1.950E-09
SKIN(FGR)   5.580E-14 7.967E-11 9.799E-10 2.850E-15-1.000E+00 0.000E+00 0.000E+00
Sb-129
GONADS      6.970E-14 2.336E-11 3.231E-11 1.440E-15-1.000E+00 2.150E-11 1.510E-10
BREAST      7.910E-14 2.222E-11 3.074E-11 1.370E-15-1.000E+00 1.280E-11 2.560E-11
LUNGS       6.980E-14 2.141E-11 2.962E-11 1.320E-15-1.000E+00 8.980E-10 9.390E-12
RED MARR    6.860E-14 2.190E-11 3.029E-11 1.350E-15-1.000E+00 1.700E-11 3.670E-11
BONE SUR    1.070E-13 3.033E-11 4.196E-11 1.870E-15-1.000E+00 1.460E-11 1.340E-11
THYROID     7.160E-14 2.174E-11 3.007E-11 1.340E-15-1.000E+00 9.720E-12 1.470E-12
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REMAINDER    6.710E-14 2.125E-11 2.939E-11 1.310E-15-1.000E+00 1.870E-10 1.450E-09
EFFECTIVE    7.140E-14 2.238E-11 3.096E-11 1.380E-15-1.000E+00 1.740E-10 4.840E-10
SKIN(FGR)    1.050E-13 8.273E-11 1.144E-10 5.100E-15-1.000E+00 0.000E+00 0.000E+00
Te-127
GONADS       2.370E-16 1.191E-13 2.661E-13 5.480E-18-1.000E+00 2.020E-12 4.020E-12
BREAST       2.730E-16 1.158E-13 2.588E-13 5.330E-18-1.000E+00 1.880E-12 3.000E-12
LUNGS        2.320E-16 1.060E-13 2.370E-13 4.880E-18-1.000E+00 4.270E-10 2.890E-12
RED MARR     2.210E-16 1.058E-13 2.365E-13 4.870E-18-1.000E+00 4.090E-12 6.570E-12
BONE SUR     4.650E-16 1.862E-13 4.162E-13 8.570E-18-1.000E+00 4.090E-12 6.460E-12
THYROID      2.400E-16 1.106E-13 2.472E-13 5.090E-18-1.000E+00 1.840E-12 2.860E-12
REMAINDER    2.210E-16 1.036E-13 2.316E-13 4.770E-18-1.000E+00 1.110E-10 6.130E-10
EFFECTIVE    2.420E-16 1.125E-13 2.515E-13 5.180E-18-1.000E+00 8.600E-11 1.870E-10
SKIN(FGR)    1.140E-14 1.173E-11 2.622E-11 5.400E-16-1.000E+00 0.000E+00 0.000E+00
Te-127m
GONADS       1.900E-16 4.689E-13 9.642E-12 1.630E-17-1.000E+00 1.100E-10 1.250E-10
BREAST       2.690E-16 5.150E-13 1.059E-11 1.790E-17-1.000E+00 1.100E-10 9.740E-11
LUNGS        7.620E-17 1.602E-13 3.295E-12 5.570E-18-1.000E+00 3.340E-08 9.620E-11
RED MARR     6.430E-17 1.249E-13 2.567E-12 4.340E-18-1.000E+00 5.360E-09 5.430E-09
BONE SUR     3.940E-16 9.005E-13 1.852E-11 3.130E-17-1.000E+00 2.040E-08 2.070E-08
THYROID      1.500E-16 2.779E-13 5.714E-12 9.660E-18-1.000E+00 9.660E-11 9.430E-11
REMAINDER    8.640E-17 1.999E-13 4.111E-12 6.950E-18-1.000E+00 1.660E-09 2.980E-09
EFFECTIVE    1.470E-16 3.251E-13 6.684E-12 1.130E-17-1.000E+00 5.810E-09 2.230E-09
SKIN(FGR)    8.490E-16 1.496E-12 3.076E-11 5.200E-17-1.000E+00 0.000E+00 0.000E+00
Te-129
GONADS       2.710E-15 3.889E-13 3.922E-13 6.510E-17-1.000E+00 5.050E-13 1.590E-12
BREAST       3.120E-15 3.800E-13 3.832E-13 6.360E-17-1.000E+00 5.390E-13 6.050E-13
LUNGS        2.640E-15 3.298E-13 3.326E-13 5.520E-17-1.000E+00 1.530E-10 4.910E-13
RED MARR     2.540E-15 3.298E-13 3.326E-13 5.520E-17-1.000E+00 6.190E-13 7.640E-13
BONE SUR     4.880E-15 5.753E-13 5.802E-13 9.630E-17-1.000E+00 6.220E-13 5.400E-13
THYROID      2.740E-15 3.525E-13 3.555E-13 5.900E-17-1.000E+00 5.090E-13 3.360E-13
REMAINDER    2.520E-15 3.262E-13 3.289E-13 5.460E-17-1.000E+00 7.280E-12 1.790E-10
EFFECTIVE    2.750E-15 3.590E-13 3.621E-13 6.010E-17-1.000E+00 2.090E-11 5.450E-11
SKIN(FGR)    3.570E-14 3.429E-11 3.458E-11 5.740E-15-1.000E+00 0.000E+00 0.000E+00
Te-129m
GONADS       3.321E-15 2.206E-12 4.799E-11 8.561E-17-1.000E+00 1.783E-10 2.420E-10
BREAST       3.838E-15 2.181E-12 4.739E-11 8.454E-17-1.000E+00 1.694E-10 1.664E-10
LUNGS        3.176E-15 1.741E-12 3.815E-11 6.808E-17-1.000E+00 4.040E-08 1.593E-10
RED MARR     3.071E-15 1.729E-12 3.793E-11 6.768E-17-1.000E+00 3.100E-09 3.500E-09
BONE SUR     5.772E-15 3.287E-12 7.147E-11 1.275E-16-1.000E+00 7.050E-09 7.990E-09
THYROID      3.341E-15 1.923E-12 4.201E-11 7.495E-17-1.000E+00 1.563E-10 1.572E-10
REMAINDER    3.048E-15 1.746E-12 3.822E-11 6.819E-17-1.000E+00 3.275E-09 7.196E-09
EFFECTIVE    3.337E-15 1.974E-12 4.308E-11 7.686E-17-1.000E+00 6.484E-09 2.925E-09
SKIN(FGR)    3.811E-14 1.501E-10 3.360E-09 6.001E-15-1.000E+00 0.000E+00 0.000E+00
Te-131m
GONADS       7.292E-14 4.020E-11 2.343E-10 1.535E-15-1.000E+00 2.345E-10 7.415E-10
BREAST       8.286E-14 3.853E-11 2.246E-10 1.472E-15-1.000E+00 9.309E-11 1.361E-10
LUNGS        7.265E-14 3.657E-11 2.131E-10 1.397E-15-1.000E+00 2.296E-09 6.335E-11
RED MARR     7.097E-14 3.736E-11 2.178E-10 1.427E-15-1.000E+00 1.417E-10 2.435E-10
BONE SUR     1.174E-13 5.467E-11 3.189E-10 2.090E-15-1.000E+00 2.276E-10 3.248E-10
THYROID      7.471E-14 3.741E-11 2.181E-10 1.429E-15-1.000E+00 3.669E-08 4.383E-08
REMAINDER    6.965E-14 3.626E-11 2.113E-10 1.385E-15-1.000E+00 9.509E-10 3.153E-10
EFFECTIVE    7.463E-14 3.825E-11 2.229E-10 1.461E-15-1.000E+00 1.758E-09 2.514E-09
SKIN(FGR)    1.038E-13 1.033E-10 6.188E-10 4.056E-15-1.000E+00 0.000E+00 0.000E+00
Te-132
GONADS       1.020E-14 6.812E-12 7.706E-11 2.450E-16-1.000E+00 4.150E-10 5.410E-10
BREAST       1.180E-14 6.756E-12 7.643E-11 2.430E-16-1.000E+00 3.630E-10 3.500E-10
LUNGS        9.650E-15 5.727E-12 6.479E-11 2.060E-16-1.000E+00 1.670E-09 3.300E-10
RED MARR     8.950E-15 5.588E-12 6.322E-11 2.010E-16-1.000E+00 4.270E-10 4.440E-10
BONE SUR     2.420E-14 1.273E-11 1.441E-10 4.580E-16-1.000E+00 7.120E-10 8.300E-10
THYROID      1.020E-14 5.978E-12 6.762E-11 2.150E-16-1.000E+00 6.280E-08 5.950E-08
REMAINDER    9.160E-15 5.644E-12 6.385E-11 2.030E-16-1.000E+00 7.890E-10 1.490E-09
EFFECTIVE    1.030E-14 6.339E-12 7.171E-11 2.280E-16-1.000E+00 2.550E-09 2.540E-09
SKIN(FGR)    1.390E-14 8.313E-12 9.405E-11 2.990E-16-1.000E+00 0.000E+00 0.000E+00
I-131
GONADS       1.780E-14 1.119E-11 1.789E-10 3.940E-16-1.000E+00 2.530E-11 4.070E-11
BREAST       2.040E-14 1.082E-11 1.730E-10 3.810E-16-1.000E+00 7.880E-11 1.210E-10
LUNGS        1.760E-14 1.016E-11 1.626E-10 3.580E-16-1.000E+00 6.570E-10 1.020E-10
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RED MARR    1.680E-14 1.022E-11 1.635E-10 3.600E-16-1.000E+00 6.260E-11 9.440E-11
BONE SUR    3.450E-14 1.675E-11 2.679E-10 5.900E-16-1.000E+00 5.730E-11 8.720E-11
THYROID     1.810E-14 1.053E-11 1.685E-10 3.710E-16-1.000E+00 2.920E-07 4.760E-07
REMAINDER   1.670E-14 9.908E-12 1.585E-10 3.490E-16-1.000E+00 8.030E-11 1.570E-10
EFFECTIVE   1.820E-14 1.067E-11 1.707E-10 3.760E-16-1.000E+00 8.890E-09 1.440E-08
SKIN(FGR)   2.980E-14 1.825E-11 2.920E-10 6.430E-16-1.000E+00 0.000E+00 0.000E+00
I-132
GONADS      1.090E-13 2.523E-11 2.771E-11 2.320E-15-1.000E+00 9.950E-12 2.330E-11
BREAST      1.240E-13 2.414E-11 2.652E-11 2.220E-15-1.000E+00 1.410E-11 2.520E-11
LUNGS       1.090E-13 2.305E-11 2.532E-11 2.120E-15-1.000E+00 2.710E-10 2.640E-11
RED MARR    1.070E-13 2.360E-11 2.592E-11 2.170E-15-1.000E+00 1.400E-11 2.460E-11
BONE SUR    1.730E-13 3.327E-11 3.655E-11 3.060E-15-1.000E+00 1.240E-11 2.190E-11
THYROID     1.120E-13 2.381E-11 2.616E-11 2.190E-15-1.000E+00 1.740E-09 3.870E-09
REMAINDER   1.050E-13 2.283E-11 2.509E-11 2.100E-15-1.000E+00 3.780E-11 1.650E-10
EFFECTIVE   1.120E-13 2.403E-11 2.640E-11 2.210E-15-1.000E+00 1.030E-10 1.820E-10
SKIN(FGR)   1.580E-13 8.199E-11 9.007E-11 7.540E-15-1.000E+00 0.000E+00 0.000E+00
I-133
GONADS      2.870E-14 1.585E-11 6.748E-11 6.270E-16-1.000E+00 1.950E-11 3.630E-11
BREAST      3.280E-14 1.519E-11 6.468E-11 6.010E-16-1.000E+00 2.940E-11 4.680E-11
LUNGS       2.860E-14 1.446E-11 6.156E-11 5.720E-16-1.000E+00 8.200E-10 4.530E-11
RED MARR    2.770E-14 1.466E-11 6.242E-11 5.800E-16-1.000E+00 2.720E-11 4.300E-11
BONE SUR    4.870E-14 2.161E-11 9.202E-11 8.550E-16-1.000E+00 2.520E-11 4.070E-11
THYROID     2.930E-14 1.502E-11 6.393E-11 5.940E-16-1.000E+00 4.860E-08 9.100E-08
REMAINDER   2.730E-14 1.418E-11 6.038E-11 5.610E-16-1.000E+00 5.000E-11 1.550E-10
EFFECTIVE   2.940E-14 1.509E-11 6.425E-11 5.970E-16-1.000E+00 1.580E-09 2.800E-09
SKIN(FGR)   5.830E-14 1.150E-10 4.897E-10 4.550E-15-1.000E+00 0.000E+00 0.000E+00
I-134
GONADS      1.270E-13 1.200E-11 1.202E-11 2.640E-15-1.000E+00 4.250E-12 1.100E-11
BREAST      1.440E-13 1.145E-11 1.147E-11 2.520E-15-1.000E+00 6.170E-12 1.170E-11
LUNGS       1.270E-13 1.100E-11 1.102E-11 2.420E-15-1.000E+00 1.430E-10 1.260E-11
RED MARR    1.250E-13 1.127E-11 1.129E-11 2.480E-15-1.000E+00 6.080E-12 1.090E-11
BONE SUR    1.960E-13 1.568E-11 1.571E-11 3.450E-15-1.000E+00 5.310E-12 9.320E-12
THYROID     1.300E-13 1.127E-11 1.129E-11 2.480E-15-1.000E+00 2.880E-10 6.210E-10
REMAINDER   1.220E-13 1.091E-11 1.093E-11 2.400E-15-1.000E+00 2.270E-11 1.340E-10
EFFECTIVE   1.300E-13 1.150E-11 1.152E-11 2.530E-15-1.000E+00 3.550E-11 6.660E-11
SKIN(FGR)   1.870E-13 4.477E-11 4.485E-11 9.850E-15-1.000E+00 0.000E+00 0.000E+00
I-135
GONADS      8.078E-14 3.113E-11 5.489E-11 1.599E-15-1.000E+00 1.700E-11 3.610E-11
BREAST      9.143E-14 2.971E-11 5.240E-11 1.526E-15-1.000E+00 2.340E-11 3.850E-11
LUNGS       8.145E-14 2.886E-11 5.089E-11 1.482E-15-1.000E+00 4.410E-10 3.750E-11
RED MARR    8.054E-14 2.965E-11 5.228E-11 1.523E-15-1.000E+00 2.240E-11 3.650E-11
BONE SUR    1.184E-13 3.983E-11 7.024E-11 2.046E-15-1.000E+00 2.010E-11 3.360E-11
THYROID     8.324E-14 2.852E-11 5.030E-11 1.465E-15-1.000E+00 8.460E-09 1.790E-08
REMAINDER   7.861E-14 2.883E-11 5.084E-11 1.481E-15-1.000E+00 4.700E-11 1.540E-10
EFFECTIVE   8.294E-14 2.989E-11 5.271E-11 1.535E-15-1.000E+00 3.320E-10 6.080E-10
SKIN(FGR)   1.156E-13 9.826E-11 1.733E-10 5.047E-15-1.000E+00 0.000E+00 0.000E+00
Xe-133
GONADS      1.610E-15 1.465E-12 2.052E-11 5.200E-17-1.000E+00 0.000E+00 0.000E+00
BREAST      1.960E-15 1.505E-12 2.107E-11 5.340E-17-1.000E+00 0.000E+00 0.000E+00
LUNGS       1.320E-15 1.045E-12 1.464E-11 3.710E-17-1.000E+00 0.000E+00 0.000E+00
RED MARR    1.070E-15 8.791E-13 1.231E-11 3.120E-17-1.000E+00 0.000E+00 0.000E+00
BONE SUR    5.130E-15 4.254E-12 5.958E-11 1.510E-16-1.000E+00 0.000E+00 0.000E+00
THYROID     1.510E-15 1.181E-12 1.653E-11 4.190E-17-1.000E+00 0.000E+00 0.000E+00
REMAINDER   1.240E-15 1.042E-12 1.460E-11 3.700E-17-1.000E+00 0.000E+00 0.000E+00
EFFECTIVE   1.560E-15 1.299E-12 1.819E-11 4.610E-17-1.000E+00 0.000E+00 0.000E+00
SKIN(FGR)   4.970E-15 1.953E-12 2.734E-11 6.930E-17-1.000E+00 0.000E+00 0.000E+00
Xe-135
GONADS      1.170E-14 5.455E-12 1.194E-11 2.530E-16-1.000E+00 0.000E+00 0.000E+00
BREAST      1.330E-14 5.325E-12 1.166E-11 2.470E-16-1.000E+00 0.000E+00 0.000E+00
LUNGS       1.130E-14 4.959E-12 1.086E-11 2.300E-16-1.000E+00 0.000E+00 0.000E+00
RED MARR    1.070E-14 4.959E-12 1.086E-11 2.300E-16-1.000E+00 0.000E+00 0.000E+00
BONE SUR    2.570E-14 9.120E-12 1.997E-11 4.230E-16-1.000E+00 0.000E+00 0.000E+00
THYROID     1.180E-14 5.023E-12 1.100E-11 2.330E-16-1.000E+00 0.000E+00 0.000E+00
REMAINDER   1.080E-14 4.829E-12 1.058E-11 2.240E-16-1.000E+00 0.000E+00 0.000E+00
EFFECTIVE   1.190E-14 5.217E-12 1.142E-11 2.420E-16-1.000E+00 0.000E+00 0.000E+00
SKIN(FGR)   3.120E-14 4.506E-11 9.867E-11 2.090E-15-1.000E+00 0.000E+00 0.000E+00
Cs-134
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GONADS       7.400E-14 4.607E-11 9.646E-10 1.600E-15-1.000E+00 1.300E-08 2.060E-08
BREAST       8.430E-14 4.406E-11 9.224E-10 1.530E-15-1.000E+00 1.080E-08 1.720E-08
LUNGS        7.370E-14 4.204E-11 8.802E-10 1.460E-15-1.000E+00 1.180E-08 1.760E-08
RED MARR     7.190E-14 4.262E-11 8.922E-10 1.480E-15-1.000E+00 1.180E-08 1.870E-08
BONE SUR     1.200E-13 6.105E-11 1.278E-09 2.120E-15-1.000E+00 1.100E-08 1.740E-08
THYROID      7.570E-14 4.377E-11 9.163E-10 1.520E-15-1.000E+00 1.110E-08 1.760E-08
REMAINDER    7.060E-14 4.147E-11 8.681E-10 1.440E-15-1.000E+00 1.390E-08 2.210E-08
EFFECTIVE    7.570E-14 4.377E-11 9.163E-10 1.520E-15-1.000E+00 1.250E-08 1.980E-08
SKIN(FGR)    9.450E-14 6.249E-11 1.308E-09 2.170E-15-1.000E+00 0.000E+00 0.000E+00
Cs-136
GONADS       1.040E-13 6.223E-11 1.102E-09 2.180E-15-1.000E+00 1.880E-09 3.040E-09
BREAST       1.180E-13 5.966E-11 1.056E-09 2.090E-15-1.000E+00 1.670E-09 2.650E-09
LUNGS        1.040E-13 5.710E-11 1.011E-09 2.000E-15-1.000E+00 2.320E-09 2.620E-09
RED MARR     1.010E-13 5.824E-11 1.031E-09 2.040E-15-1.000E+00 1.860E-09 2.950E-09
BONE SUR     1.660E-13 8.422E-11 1.491E-09 2.950E-15-1.000E+00 1.700E-09 2.710E-09
THYROID      1.070E-13 5.852E-11 1.036E-09 2.050E-15-1.000E+00 1.730E-09 2.740E-09
REMAINDER    9.950E-14 5.652E-11 1.001E-09 1.980E-15-1.000E+00 2.190E-09 3.520E-09
EFFECTIVE    1.060E-13 5.966E-11 1.056E-09 2.090E-15-1.000E+00 1.980E-09 3.040E-09
SKIN(FGR)    1.250E-13 7.251E-11 1.284E-09 2.540E-15-1.000E+00 0.000E+00 0.000E+00
Cs-137
GONADS       2.669E-14 1.669E-11 3.530E-10 5.840E-16-1.000E+00 8.760E-09 1.390E-08
BREAST       3.047E-14 1.596E-11 3.376E-10 5.585E-16-1.000E+00 7.840E-09 1.240E-08
LUNGS        2.649E-14 1.517E-11 3.209E-10 5.309E-16-1.000E+00 8.820E-09 1.270E-08
RED MARR     2.583E-14 1.542E-11 3.260E-10 5.394E-16-1.000E+00 8.300E-09 1.320E-08
BONE SUR     4.382E-14 2.238E-11 4.734E-10 7.832E-16-1.000E+00 7.940E-09 1.260E-08
THYROID      2.725E-14 1.588E-11 3.358E-10 5.556E-16-1.000E+00 7.930E-09 1.260E-08
REMAINDER    2.536E-14 1.490E-11 3.152E-10 5.215E-16-1.000E+00 9.120E-09 1.450E-08
EFFECTIVE    2.725E-14 1.585E-11 3.353E-10 5.546E-16-1.000E+00 8.630E-09 1.350E-08
SKIN(FGR)    4.392E-14 5.253E-11 1.110E-09 1.836E-15-1.000E+00 0.000E+00 0.000E+00
Ba-139
GONADS       2.130E-15 3.368E-13 3.429E-13 4.790E-17-1.000E+00 2.560E-12 1.560E-12
BREAST       2.450E-15 3.297E-13 3.357E-13 4.690E-17-1.000E+00 2.460E-12 5.170E-13
LUNGS        2.030E-15 3.002E-13 3.057E-13 4.270E-17-1.000E+00 2.530E-10 3.890E-13
RED MARR     1.870E-15 2.932E-13 2.985E-13 4.170E-17-1.000E+00 3.410E-12 8.590E-13
BONE SUR     5.290E-15 6.841E-13 6.965E-13 9.730E-17-1.000E+00 2.490E-12 4.380E-13
THYROID      2.130E-15 3.044E-13 3.100E-13 4.330E-17-1.000E+00 2.400E-12 2.660E-13
REMAINDER    1.920E-15 2.932E-13 2.985E-13 4.170E-17-1.000E+00 4.820E-11 3.570E-10
EFFECTIVE    2.170E-15 3.227E-13 3.286E-13 4.590E-17-1.000E+00 4.640E-11 1.080E-10
SKIN(FGR)    6.160E-14 7.241E-11 7.373E-11 1.030E-14-1.000E+00 0.000E+00 0.000E+00
Ba-140
GONADS       8.410E-15 5.451E-12 9.607E-11 1.910E-16-1.000E+00 4.300E-10 9.960E-10
BREAST       9.640E-15 5.280E-12 9.305E-11 1.850E-16-1.000E+00 2.870E-10 1.590E-10
LUNGS        8.270E-15 4.852E-12 8.550E-11 1.700E-16-1.000E+00 1.660E-09 6.630E-11
RED MARR     7.930E-15 4.880E-12 8.601E-11 1.710E-16-1.000E+00 1.290E-09 4.390E-10
BONE SUR     1.550E-14 8.020E-12 1.413E-10 2.810E-16-1.000E+00 2.410E-09 5.530E-10
THYROID      8.530E-15 5.109E-12 9.003E-11 1.790E-16-1.000E+00 2.560E-10 5.250E-11
REMAINDER    7.890E-15 4.766E-12 8.399E-11 1.670E-16-1.000E+00 1.410E-09 7.370E-09
EFFECTIVE    8.580E-15 5.137E-12 9.053E-11 1.800E-16-1.000E+00 1.010E-09 2.560E-09
SKIN(FGR)    2.520E-14 5.565E-11 9.808E-10 1.950E-15-1.000E+00 0.000E+00 0.000E+00
La-140
GONADS       1.140E-13 6.027E-11 4.425E-10 2.240E-15-1.000E+00 4.540E-10 1.340E-09
BREAST       1.290E-13 5.758E-11 4.228E-10 2.140E-15-1.000E+00 1.450E-10 1.800E-10
LUNGS        1.150E-13 5.596E-11 4.109E-10 2.080E-15-1.000E+00 4.210E-09 4.010E-11
RED MARR     1.140E-13 5.731E-11 4.208E-10 2.130E-15-1.000E+00 2.140E-10 2.810E-10
BONE SUR     1.690E-13 7.776E-11 5.709E-10 2.890E-15-1.000E+00 1.410E-10 9.770E-11
THYROID      1.180E-13 5.462E-11 4.010E-10 2.030E-15-1.000E+00 6.870E-11 6.400E-12
REMAINDER    1.110E-13 5.569E-11 4.089E-10 2.070E-15-1.000E+00 2.120E-09 6.260E-09
EFFECTIVE    1.170E-13 5.812E-11 4.267E-10 2.160E-15-1.000E+00 1.310E-09 2.280E-09
SKIN(FGR)    1.660E-13 2.217E-10 1.628E-09 8.240E-15-1.000E+00 0.000E+00 0.000E+00
La-141
GONADS       2.330E-15 7.315E-13 9.675E-13 4.740E-17-1.000E+00 1.010E-11 3.770E-12
BREAST       2.640E-15 7.007E-13 9.267E-13 4.540E-17-1.000E+00 9.840E-12 7.070E-13
LUNGS        2.340E-15 6.713E-13 8.879E-13 4.350E-17-1.000E+00 6.460E-10 2.720E-13
RED MARR     2.310E-15 6.852E-13 9.063E-13 4.440E-17-1.000E+00 2.930E-11 1.070E-12
BONE SUR     3.490E-15 9.923E-13 1.312E-12 6.430E-17-1.000E+00 1.200E-10 6.060E-13
THYROID      2.390E-15 6.590E-13 8.716E-13 4.270E-17-1.000E+00 9.400E-12 5.290E-14
REMAINDER    2.260E-15 6.682E-13 8.838E-13 4.330E-17-1.000E+00 2.280E-10 1.240E-09
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EFFECTIVE      2.390E-15 7.007E-13 9.267E-13 4.540E-17-1.000E+00 1.570E-10 3.740E-10
SKIN(FGR)      6.580E-14 1.667E-10 2.204E-10 1.080E-14-1.000E+00 0.000E+00 0.000E+00
La-142
GONADS         1.400E-13 1.978E-11 2.034E-11 2.540E-15-1.000E+00 1.660E-11 6.990E-11
BREAST         1.570E-13 1.885E-11 1.938E-11 2.420E-15-1.000E+00 1.130E-11 1.540E-11
LUNGS          1.420E-13 1.846E-11 1.898E-11 2.370E-15-1.000E+00 3.010E-10 8.400E-12
RED MARR       1.420E-13 1.900E-11 1.954E-11 2.440E-15-1.000E+00 1.360E-11 1.930E-11
BONE SUR       1.950E-13 2.484E-11 2.554E-11 3.190E-15-1.000E+00 1.110E-11 7.400E-12
THYROID        1.450E-13 1.768E-11 1.818E-11 2.270E-15-1.000E+00 8.740E-12 1.160E-12
REMAINDER      1.380E-13 1.853E-11 1.906E-11 2.380E-15-1.000E+00 8.070E-11 5.200E-10
EFFECTIVE      1.440E-13 1.916E-11 1.970E-11 2.460E-15-1.000E+00 6.840E-11 1.790E-10
SKIN(FGR)      2.160E-13 9.111E-11 9.368E-11 1.170E-14-1.000E+00 0.000E+00 0.000E+00
Ce-141
GONADS         3.380E-15 2.213E-12 4.332E-11 7.710E-17-1.000E+00 5.540E-11 1.080E-10
BREAST         3.930E-15 2.170E-12 4.247E-11 7.560E-17-1.000E+00 4.460E-11 1.110E-11
LUNGS          3.170E-15 1.951E-12 3.820E-11 6.800E-17-1.000E+00 1.670E-08 1.430E-12
RED MARR       2.830E-15 1.860E-12 3.641E-11 6.480E-17-1.000E+00 8.960E-11 3.390E-11
BONE SUR       9.410E-15 5.166E-12 1.011E-10 1.800E-16-1.000E+00 2.540E-10 2.300E-11
THYROID        3.350E-15 2.003E-12 3.922E-11 6.980E-17-1.000E+00 2.550E-11 1.800E-13
REMAINDER      2.980E-15 1.894E-12 3.708E-11 6.600E-17-1.000E+00 1.260E-09 2.500E-09
EFFECTIVE      3.430E-15 2.118E-12 4.146E-11 7.380E-17-1.000E+00 2.420E-09 7.830E-10
SKIN(FGR)      1.020E-14 3.788E-12 7.416E-11 1.320E-16-1.000E+00 0.000E+00 0.000E+00
Ce-143
GONADS         1.280E-14 7.900E-12 4.958E-11 2.980E-16-1.000E+00 7.530E-11 2.120E-10
BREAST         1.470E-14 7.688E-12 4.825E-11 2.900E-16-1.000E+00 1.660E-11 2.320E-11
LUNGS          1.230E-14 6.893E-12 4.325E-11 2.600E-16-1.000E+00 3.880E-09 3.820E-12
RED MARR       1.170E-14 6.787E-12 4.259E-11 2.560E-16-1.000E+00 2.960E-11 5.070E-11
BONE SUR       2.520E-14 1.323E-11 8.302E-11 4.990E-16-1.000E+00 1.640E-11 1.610E-11
THYROID        1.280E-14 7.211E-12 4.525E-11 2.720E-16-1.000E+00 6.230E-12 4.350E-13
REMAINDER      1.170E-14 6.734E-12 4.226E-11 2.540E-16-1.000E+00 1.420E-09 3.890E-09
EFFECTIVE      1.290E-14 7.396E-12 4.642E-11 2.790E-16-1.000E+00 9.160E-10 1.230E-09
SKIN(FGR)      3.960E-14 1.058E-10 6.638E-10 3.990E-15-1.000E+00 0.000E+00 0.000E+00
Ce-144
GONADS         2.725E-15 6.328E-13 1.319E-11 6.088E-17-1.000E+00 2.390E-10 6.987E-11
BREAST         3.129E-15 6.274E-13 1.307E-11 5.922E-17-1.000E+00 3.480E-10 1.223E-11
LUNGS          2.639E-15 5.228E-13 1.089E-11 5.362E-17-1.000E+00 7.911E-07 6.551E-12
RED MARR       2.507E-15 4.755E-13 9.907E-12 5.247E-17-1.000E+00 2.880E-09 8.923E-11
BONE SUR       5.441E-15 1.646E-12 3.429E-11 1.127E-16-1.000E+00 4.720E-09 1.280E-10
THYROID        2.753E-15 5.529E-13 1.152E-11 5.418E-17-1.000E+00 2.920E-10 5.154E-12
REMAINDER      2.534E-15 5.086E-13 1.060E-11 5.283E-17-1.000E+00 1.910E-08 1.890E-08
EFFECTIVE      2.773E-15 5.909E-13 1.231E-11 5.766E-17-1.000E+00 1.010E-07 5.711E-09
SKIN(FGR)      8.574E-14 7.648E-13 1.594E-11 1.250E-14-1.000E+00 0.000E+00 0.000E+00
Pr-143
GONADS         2.130E-17 2.264E-14 4.032E-13 7.930E-19-1.000E+00 4.370E-18 8.990E-18
BREAST         2.550E-17 2.330E-14 4.149E-13 8.160E-19-1.000E+00 2.220E-18 1.090E-18
LUNGS          1.860E-17 1.642E-14 2.923E-13 5.750E-19-1.000E+00 1.330E-08 1.910E-19
RED MARR       1.620E-17 1.493E-14 2.659E-13 5.230E-19-1.000E+00 1.480E-11 1.030E-12
BONE SUR       5.930E-17 5.454E-14 9.711E-13 1.910E-18-1.000E+00 1.490E-11 1.030E-12
THYROID        2.050E-17 1.802E-14 3.208E-13 6.310E-19-1.000E+00 1.680E-18 2.660E-20
REMAINDER      1.760E-17 1.642E-14 2.923E-13 5.750E-19-1.000E+00 1.970E-09 4.220E-09
EFFECTIVE      2.100E-17 2.002E-14 3.564E-13 7.010E-19-1.000E+00 2.190E-09 1.270E-09
SKIN(FGR)      1.760E-14 5.711E-11 1.017E-09 2.000E-15-1.000E+00 0.000E+00 0.000E+00
Nd-147
GONADS         6.130E-15 4.218E-12 7.235E-11 1.480E-16-1.000E+00 8.410E-11 1.790E-10
BREAST         7.120E-15 4.132E-12 7.088E-11 1.450E-16-1.000E+00 3.450E-11 1.870E-11
LUNGS          5.820E-15 3.648E-12 6.257E-11 1.280E-16-1.000E+00 1.060E-08 2.440E-12
RED MARR       5.400E-15 3.505E-12 6.013E-11 1.230E-16-1.000E+00 9.190E-11 5.050E-11
BONE SUR       1.320E-14 8.265E-12 1.418E-10 2.900E-16-1.000E+00 3.260E-10 2.220E-11
THYROID        6.120E-15 3.876E-12 6.648E-11 1.360E-16-1.000E+00 1.820E-11 2.640E-13
REMAINDER      5.530E-15 3.562E-12 6.111E-11 1.250E-16-1.000E+00 1.760E-09 3.760E-09
EFFECTIVE      6.190E-15 3.961E-12 6.795E-11 1.390E-16-1.000E+00 1.850E-09 1.180E-09
SKIN(FGR)      1.950E-14 3.135E-11 5.377E-10 1.100E-15-1.000E+00 0.000E+00 0.000E+00
Np-239
GONADS         7.530E-15 4.691E-12 4.380E-11 1.710E-16-1.000E+00 7.450E-11 1.620E-10
BREAST         8.730E-15 4.636E-12 4.329E-11 1.690E-16-1.000E+00 1.630E-11 1.720E-11
LUNGS          7.180E-15 4.115E-12 3.842E-11 1.500E-16-1.000E+00 2.360E-09 2.400E-12
RED MARR       6.500E-15 4.005E-12 3.740E-11 1.460E-16-1.000E+00 2.080E-10 4.660E-11
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BONE SUR    2.000E-14 1.001E-11 9.349E-11 3.650E-16-1.000E+00 2.030E-09 3.590E-11
THYROID     7.520E-15 4.197E-12 3.919E-11 1.530E-16-1.000E+00 7.620E-12 2.070E-13
REMAINDER   6.760E-15 4.005E-12 3.740E-11 1.460E-16-1.000E+00 9.590E-10 2.770E-09
EFFECTIVE   7.690E-15 4.471E-12 4.175E-11 1.630E-16-1.000E+00 6.780E-10 8.820E-10
SKIN(FGR)   1.600E-14 7.215E-12 6.737E-11 2.630E-16-1.000E+00 0.000E+00 0.000E+00
Pu-238
GONADS      6.560E-18 4.291E-14 9.011E-13 1.490E-18-1.000E+00 1.040E-05 2.330E-09
BREAST      1.270E-17 5.558E-14 1.167E-12 1.930E-18-1.000E+00 4.400E-10 1.800E-13
LUNGS       1.060E-18 2.267E-15 4.759E-14 7.870E-20-1.000E+00 3.200E-04 8.640E-14
RED MARR    1.680E-18 5.587E-15 1.173E-13 1.940E-19-1.000E+00 5.800E-05 1.270E-08
BONE SUR    9.300E-18 3.514E-14 7.378E-13 1.220E-18-1.000E+00 7.250E-04 1.580E-07
THYROID     4.010E-18 9.792E-15 2.056E-13 3.400E-19-1.000E+00 3.860E-10 7.990E-14
REMAINDER   1.990E-18 9.216E-15 1.935E-13 3.200E-19-1.000E+00 2.740E-05 2.180E-08
EFFECTIVE   4.880E-18 2.413E-14 5.068E-13 8.380E-19-1.000E+00 7.790E-05 1.340E-08
SKIN(FGR)   4.090E-17 2.776E-13 5.830E-12 9.640E-18-1.000E+00 0.000E+00 0.000E+00
Pu-239
GONADS      4.840E-18 1.768E-14 3.713E-13 6.140E-19-1.000E+00 1.200E-05 2.640E-09
BREAST      7.550E-18 2.238E-14 4.699E-13 7.770E-19-1.000E+00 3.990E-10 1.210E-13
LUNGS       2.650E-18 2.267E-15 4.760E-14 7.870E-20-1.000E+00 3.230E-04 7.890E-14
RED MARR    2.670E-18 3.456E-15 7.258E-14 1.200E-19-1.000E+00 6.570E-05 1.410E-08
BONE SUR    9.470E-18 1.673E-14 3.514E-13 5.810E-19-1.000E+00 8.210E-04 1.760E-07
THYROID     3.880E-18 5.126E-15 1.077E-13 1.780E-19-1.000E+00 3.750E-10 7.500E-14
REMAINDER   2.860E-18 4.838E-15 1.016E-13 1.680E-19-1.000E+00 3.020E-05 2.120E-08
EFFECTIVE   4.240E-18 1.057E-14 2.220E-13 3.670E-19-1.000E+00 8.330E-05 1.400E-08
SKIN(FGR)   1.860E-17 1.057E-13 2.220E-12 3.670E-18-1.000E+00 0.000E+00 0.000E+00
Pu-240
GONADS      6.360E-18 4.118E-14 8.649E-13 1.430E-18-1.000E+00 1.200E-05 2.640E-09
BREAST      1.230E-17 5.328E-14 1.119E-12 1.850E-18-1.000E+00 4.330E-10 1.730E-13
LUNGS       1.090E-18 2.249E-15 4.723E-14 7.810E-20-1.000E+00 3.230E-04 8.220E-14
RED MARR    1.650E-18 5.386E-15 1.131E-13 1.870E-19-1.000E+00 6.570E-05 1.410E-08
BONE SUR    9.260E-18 3.398E-14 7.137E-13 1.180E-18-1.000E+00 8.210E-04 1.760E-07
THYROID     3.920E-18 9.446E-15 1.984E-13 3.280E-19-1.000E+00 3.760E-10 7.510E-14
REMAINDER   1.960E-18 8.870E-15 1.863E-13 3.080E-19-1.000E+00 3.020E-05 2.130E-08
EFFECTIVE   4.750E-18 2.313E-14 4.857E-13 8.030E-19-1.000E+00 8.330E-05 1.400E-08
SKIN(FGR)   3.920E-17 2.644E-13 5.552E-12 9.180E-18-1.000E+00 0.000E+00 0.000E+00
Pu-241
GONADS      7.190E-20 6.653E-17 1.396E-15 2.310E-21-1.000E+00 2.760E-07 5.660E-11
BREAST      8.670E-20 7.229E-17 1.517E-15 2.510E-21-1.000E+00 2.140E-11 2.790E-15
LUNGS       6.480E-20 4.090E-17 8.584E-16 1.420E-21-1.000E+00 3.180E-06 4.480E-15
RED MARR    5.630E-20 4.003E-17 8.403E-16 1.390E-21-1.000E+00 1.430E-06 2.780E-10
BONE SUR    2.190E-19 1.385E-16 2.908E-15 4.810E-21-1.000E+00 1.780E-05 3.480E-09
THYROID     6.980E-20 4.522E-17 9.491E-16 1.570E-21-1.000E+00 9.150E-12 1.010E-15
REMAINDER   6.090E-20 4.291E-17 9.007E-16 1.490E-21-1.000E+00 6.020E-07 1.850E-10
EFFECTIVE   7.250E-20 5.558E-17 1.167E-15 1.930E-21-1.000E+00 1.340E-06 2.070E-10
SKIN(FGR)   1.170E-19 2.033E-16 4.268E-15 7.060E-21-1.000E+00 0.000E+00 0.000E+00
Am-241
GONADS      8.580E-16 9.360E-13 1.966E-11 3.250E-17-1.000E+00 3.250E-05 2.700E-07
BREAST      1.070E-15 1.014E-12 2.129E-11 3.520E-17-1.000E+00 2.670E-09 2.620E-11
LUNGS       6.740E-16 5.789E-13 1.216E-11 2.010E-17-1.000E+00 1.840E-05 3.360E-11
RED MARR    5.210E-16 4.838E-13 1.016E-11 1.680E-17-1.000E+00 1.740E-04 1.450E-06
BONE SUR    2.870E-15 2.678E-12 5.625E-11 9.300E-17-1.000E+00 2.170E-03 1.810E-05
THYROID     7.830E-16 6.365E-13 1.337E-11 2.210E-17-1.000E+00 1.600E-09 1.320E-11
REMAINDER   6.340E-16 5.933E-13 1.246E-11 2.060E-17-1.000E+00 7.820E-05 6.660E-07
EFFECTIVE   8.180E-16 7.920E-13 1.663E-11 2.750E-17-1.000E+00 1.200E-04 9.840E-07
SKIN(FGR)   1.280E-15 2.396E-12 5.032E-11 8.320E-17-1.000E+00 0.000E+00 0.000E+00
Cm-242
GONADS      7.830E-18 4.893E-14 1.013E-12 1.700E-18-1.000E+00 5.700E-07 5.200E-09
BREAST      1.480E-17 6.159E-14 1.275E-12 2.140E-18-1.000E+00 9.440E-10 8.950E-12
LUNGS       1.130E-18 3.022E-15 6.257E-14 1.050E-19-1.000E+00 1.550E-05 8.840E-12
RED MARR    1.890E-18 6.562E-15 1.359E-13 2.280E-19-1.000E+00 3.900E-06 3.570E-08
BONE SUR    1.060E-17 4.231E-14 8.759E-13 1.470E-18-1.000E+00 4.870E-05 4.460E-07
THYROID     4.910E-18 1.261E-14 2.610E-13 4.380E-19-1.000E+00 9.410E-10 8.820E-12
REMAINDER   2.270E-18 1.079E-14 2.235E-13 3.750E-19-1.000E+00 2.450E-06 4.020E-08
EFFECTIVE   5.690E-18 2.751E-14 5.697E-13 9.560E-19-1.000E+00 4.670E-06 3.100E-08
SKIN(FGR)   4.290E-17 2.700E-13 5.589E-12 9.380E-18-1.000E+00 0.000E+00 0.000E+00
Cm-244
GONADS      6.900E-18 4.522E-14 9.492E-13 1.570E-18-1.000E+00 1.590E-05 1.330E-07
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BREAST      1.330E-17 5.702E-14 1.197E-12 1.980E-18-1.000E+00 1.040E-09 8.820E-12
LUNGS       7.080E-19 2.592E-15 5.441E-14 9.000E-20-1.000E+00 1.930E-05 8.810E-12
RED MARR    1.460E-18 5.875E-15 1.233E-13 2.040E-19-1.000E+00 9.380E-05 7.820E-07
BONE SUR    8.820E-18 3.859E-14 8.101E-13 1.340E-18-1.000E+00 1.170E-03 9.770E-06
THYROID     4.190E-18 1.146E-14 2.406E-13 3.980E-19-1.000E+00 1.010E-09 8.440E-12
REMAINDER   1.810E-18 9.821E-15 2.062E-13 3.410E-19-1.000E+00 4.780E-05 4.150E-07
EFFECTIVE   4.910E-18 2.529E-14 5.308E-13 8.780E-19-1.000E+00 6.700E-05 5.450E-07
SKIN(FGR)   3.910E-17 2.506E-13 5.260E-12 8.700E-18-1.000E+00 0.000E+00 0.000E+00
```

These values are stored in file "FGR60.INP".
The half lives and atomic weights for these 60 isotopes are stored in file
"FGR60.NIF."

1.4.3.4 Plant Model File

After the input to screens 0000 through 1900 discussed in Section 1.4 has been entered, it is saved as a plant model file. The user may use this file as one of the two files needed to run RADTRAD in batch mode. The format of the file is detailed below and a sample file is then listed.

Plant model file name format (standard MS-DOS rules apply): *filename*.**PMF**

Plant model file format and variable names

Plain text or *variable name*	Format	Comments
Plant Model Name:	1x, a19	
plant_model_name	a40	printable ASCII characters
Nuclide Inventory File:	1x, a21	
inventory_filename	a9	file name suffix must be NIF and standard MS-DOS device name, path, and file name rules apply
Plant Power Level:	1x, a20	
plant_power_level	f11.4	units = megawatts – thermal valid range $\geq$ > 0.0
Compartments:	1x, a25	
number_of_compartments	i2	valid range = 0 to 10 inclusive

For each compartment n = 1 to number_of_compartments

Compartment *n*:	1x, a12,i1,a1	
compartment_name(n)	a40	printable ASCII characters
compartment_type(n)	1x,i1	1 = normal compartment, 2 = control room, 3 = environment
compartment_volume(n)	1x, e11.4	units = meter^3 valid range > 0.0
compartment_sprays(n)	1x, i1	0 = sprays not present 1 = sprays present
compartment_sump(n)	1x, i1	0 = sump not present 1 = sump present
compartment_filters(n)	1x, i1	0 = recirculating filters not present 1 = recirculating filters present

compartment_deposition(n)	1x, i1	0 = natural deposition does not occur
		1 = natural deposition does occur
compartment_opool(n)		0 = natural deposition does not occur
		1 = natural deposition does occur

Finish for all compartments used

Pathways: 1x, a9

number_of_pathways i2 valid range = 0 to 99 inclusive

For each compartment-to-compartment pathway n = 1 to number of pathways

Pathway(n) =	1x, a9,I2,a4	
pathway_name(1)	a40	printable ASCII characters
pathway_from(1)	i2	valid range = 1 to *number_of_compartments* inclusive
pathway_to(1)	i2	valid range = 1 to *number_of_compartments* inclusive
pathway_type(1)	I1	1 = piping
		2 = filtered pathway
		3 = suppression pool
		4 = natural convection

Finish for all pathways used

End of plant model file

1.4.3.4.1 Acceptance Test Case #24 PMF File

```
Plant Model Name:

Nuclide Inventory File:
DEFAULTS\PWR_DEF.NIF
Plant Power Level:
 0.3992E+04
Compartments:
   5
Compartment  1:
Sprayed Region
   3
 0.2740E+07
   1
   0
   0
   0
   0
Compartment  2:
Unsprayed Region
   3
 0.6011E+06
   0
   0
   0
   1
   0
Compartment  3:
Annulus
   3
 0.6162E+06
   0
   0
   0
   0
   0
Compartment  4:
Environment
   2
 0.1653E+12
   0
   0
   0
   0
   0
Compartment  5:
Control Room
   1
 0.6731E+05
   0
   0
   1
   0
   0
Pathways:
 10
Pathway    1:
Sprayed to Unsprayed
   1
   2
   4
Pathway    2:
Sprayed to Annulus
   1
   3
```

```
    4
Pathway   3:
Sprayed to Environment
    1
    4
    4
Pathway   4:
Unsprayed to Sprayed
    2
    1
    4
Pathway   5:
Unsprayed to Annulus
    2
    3
    4
Pathway   6:
Unsprayed to Environment
    2
    4
    4
Pathway   7:
Annulus to Environment
    3
    4
    1
Pathway   8:
Filter 3--Environment to CR
    4
    5
    2
Pathway   9:
Unfiltered--Environment to CR
    4
    5
    2
Pathway  10:
Exhaust from CR to Environment
    5
    4
    2
End of Plant Model File
```

1.4.3.5 Scenario Description File

After the input to screens 2000 through 2900 discussed in Section 1.4 has been entered, it is saved as a scenario description file. The user may use this file as one of the two files needed to run RADTRAD in batch mode. The format of the file is detailed below and a sample file is then listed.

Scenario description file name format (standard MS-DOS rules apply): *filename*.**SDF**

Scenario description file format and variable names

Plain text or *variable name*	Format	Comments
Scenario Description Name:	1x, a26	
scenario_name	1x, a40	printable ASCII characters
Plant Model File Name:	1x, a21	
plant_model_filename	1x, a40	file name suffix must be PMF and standard MS-DOS device name, path, and file name rules apply
Source Term:	1x, a12	
source_term_compartment	1x, i3	valid range = 1 to number_of_compartments
dose_conversion_filename		
	1x, a18	file names suffix must be DAT and standard MS-DOS device name, path, and file name rules apply.
release_filename	1x, a40	file name suffix must be RFT and standard MS-DOS device name, path, and file name rules apply
delay_time	1x, e11.4	valid range = > 0.0 hours
calculate_daughters	1x, i3	0 = no daughters are calculated 1 = all daughters are calculated
i_fraction_aerosol	1x,e11.4	valid range = 0.0 to 1.0

i_fraction_elemental	e11.4	valid range = 0.0 to 1.0
i_fraction_organic	e11.4	valid range = 0.0 to 1.0
		these three variables should total 1.0
i_fraction_radioactive	e11.4	valid range = 0.0 to 1.0
		these four variables appear on the same line in the file

Overlying Pool: 1x, a15

op_decay	1x, i3	0 = no decay chain processing
		1 = decay chain processing
op_initial_volume	1x, e11.4	units = cubic meters
		valid range > = 0.0
op_aerosol_model	1x, i3	0 = no aerosol removal
		1 = user-specified decontamination factors
		2 = decontamination factors calculated using the Powers model

These lines will be included if and only if the user-specified (*op_aerosol_model* = 1) decontamination factors are used.

op_aerosol_count	1x, i3	valid range = 1 to 25 inclusive
op_aerosol_time(n)		units = hours
op_aerosol_df(n)	2(1x, e11.4)	valid range = 0.0 to 1.0
		these two variables appear in the file on the same line. Enter for n=1,op_aerosol_count

End of user-specified decontamination factors.

These lines will be included if the Powers model (*op_aerosol_model* = 2.) for calculating the decontamination factors is used.

op_aerosol_percentile	1x, e11.4	10.0 = 10th percentile model
		50.0 = 50th percentile model
		90.0 = 90th percentile model
op_aerosol_count	1x, i3	valid range = 1 to 25 inclusive
op_aerosol_time(n)		units = hours
op_aerosol_height(n)		units = meters

| *op_aerosol_cooling(n)* | 3(1x, e11.4) | units = K
these three variables appear on the same line in the file |

End of Powers model-calculated decontamination factors.

| *op_elemental_model* | 1x, i3 | 0 = no elemental iodine removal
1 = user-specified decontamination factors
2 = decontamination factors calculated using a model (no model is available at this time) |

These lines will be included if and only if user-specified (*op_elemental_model* = 1) decontamination factors are used.

| *op_elemental_count* | 1x, i3 | valid range = 1 to 25 inclusive |

| *op_elemental_time(1)* | | units = hours |
| *op_elemental_df(1)* | 2(1x, e11.4) | valid range = 0.0 to 1.0
these two variables appear on the same line in the file |

| *op_elemental_time(n)* | | |
| *op_elemental_df(n)* | | n = *op_elemental_df_count* |

End of user-specified decontamination factors.

| *op_organic_model* | 1x, i3 | 0 = no organic iodine removal
1 = user-specified decontamination factors
2 = decontamination factors calculated using a model (no model is available at this time) |

These lines will be included if and only if user-specified (*op_organic_model* = 1) decontamination factors are used.

| *op_organic_count* | 1x, i3 | valid range = 0 to 25 inclusive
0 = no organic iodine decontamination
1-25 = number of decontamination factors |

op_organic_time(n)		units = hours
op_organic_dfn1)	2(1x, e11.4)	valid range = 0.0 to 1.0
		These two variables appear on the same line in the file; input for n=1,op_organic_count

End of user-specified decontamination factors.

op_volatilization_model	1x, i3	0 = no iodine volatilization

Compartments: 1x, a13

number_of_compartments	1x, i3	valid range = the number of compartments specified in the plant model file

Compartment n: 1x, a12,i2,a1 valid range = 1 to number_of_compartments

compartment_detail(n)	1x, i3	0 = no detail output printed
		1 = detail output printed
compartment_decay(n)	1x, i3	0 = no decay chain processing
		1 = decay chain processing
sprays_aerosol_count(n)	1x, i3	0 = no aerosol removal
		1-25 = number of aerosol removal coefficients supplied or calculated

These lines will be included if the user-specified (*sprays_aerosol_count(n)* > 0)

sprays_aerosol_model(n)	1x, i3	1 = user-specified aerosol removal coefficients
		2 = aerosol removal coefficients calculated using the Powers model

These lines will be included if the user-specified (*sprays_aerosol_model(n)* = 1) removal coefficients are used and *sprays_aerosol_count(n)* is nonzero.

sprays_aerosol_time(n)(m)		units = hours
sprays_aerosol(n)(m)	2(1x, e11.4)	units = per second
		These two variables appear on the

same line in the file; input for up to 5 sets of data.

End of user-specified decontamination factors.

These lines will be included if the Powers model (*sprays_aerosol_model(1)* = 2.) for calculating the decontamination factors is used and *sprays_aerosol_count(1)* is nonzero.

sprays_aerosol_percentile(1)	1x, e11.4	$10.0 = 10^{th}$ percentile model
		$50.0 = 50^{th}$ percentile model
		$90.0 = 90^{th}$ percentile model
sprays_aerosol_time(n)(m)		units = hours
sprays_aerosol_flux(n)(m)		units = cubic meters of water per square meter per second
sprays_aerosol_height(n)(m)	3(1x, e11.4)	units = meters
		these three variables appear on the same line in the file

End of Powers model-calculated removal coefficients.

sprays_elemental_count(n)	1x, i3	valid range = 0 to 25 inclusive
		0 = no elemental iodine removal
		1-25 = number of removal coefficients
sprays_elemental_time(1)(1)		units = hours
sprays_elemental(1)(1)	2(1x, e11.4)	valid range = 0.0 to 1.0
		these two variables appear on the same line in the file
sprays_elemental_time(1)(n)		
sprays_elemental(1)(n)		n = *sprays_elemental_count(1)*
sprays_organic_count(1)	1x, i3	valid range = 0 to 25 inclusive
		0 = no organic iodine decontamination
		1-25 = number of decontamination factors supplied
sprays_organic_time(1)(1)		units = hours

sprays_organic(1)(1)	2(1x, e11.4)	valid range = 0.0 to 1.0 these two variables appear on the same line in the file
sprays_organic_time(1)(n) *sprays_organic(1)(n)*		n = *sprays_organic_count(1)*
sump_volatilization_count(1)	1x, i3	0 = no iodine volatilization
c_filter_norm_flow_rate(1)	1x, e11.4	units = per second
c_filter_eff_count(1)	1x, i3	valid range = 0 to 25 inclusive 0 = no filter action 1-25 = number of filter efficiencies
c_filter_aerosol_eff(1)(1)		units = percent valid range = 0.0 to 100.0 inclusive
c_filter_elemental_eff(1)(1)		units = percent valid range = 0.0 to 100.0 inclusive
c_filter_organic_eff(1)(1)	3(1x, e11.4)	units = percent valid range = 0.0 to 100.0 inclusive these three variables appear on the same line in the file
c_filter_aerosol_eff(1)(n) *c_filter_elemental_eff(1)(n)* *c_filter_organic_eff(1)(n)*		n = *c_filter_eff_count(1)*
deposit_aerosol_count(1)	1x, i3	valid range = 0 to 25 inclusive 0 = no aerosol removal 1-25 = number of aerosol removal coefficients supplied or calculated
deposit_aerosol_model(1)	1x, i3	valid range = 1 to 2 inclusive 1 = user-specified aerosol removal coefficients 2 = aerosol removal coefficients calculated using the Henry model

These lines will be included if the user-specified (*deposit_aerosol_model(1)* = 1) removal coefficients are used and *deposit_aerosol_count(1)* is nonzero.

deposit_aerosol_time(1)(1)		units = hours

deposit_aerosol(1)(1)	2(1x, e11.4)	units = per second
		these two variables appear on the
		same line in the file

deposit_aerosol_time(1)(n)
deposit_aerosol(1)(n) $n = deposit\_aerosol\_count(1)$

End of user-specified decontamination factors.

No lines will be included if the Henry model (*deposit_aerosol_model(1) = 2.*) for calculating the decontamination factors is used or *sprays_aerosol_count(1)* is zero.

deposit_elemental_count(1)	1x, i3	valid range = 0 to 25 inclusive
		0 = no elemental iodine removal
		1-25 = number of aerosol removal
		coefficients supplied or calculated

deposit_elemental_time(1)(1)		units = hours
deposit_elemental(1)(1)	2(1x, e11.4)	units = per second
		these two variables appear on the
		same line in the file

deposit_elemental_time(1)(n)
deposit_elemental(1)(n) $n = deposit\_elemental\_count(1)$

Compartment m:

compartment_detail(m)

compartment_decay(m)

deposit_elemental_time(m)(n) $m = number\_of\_compartments$
deposit_elemental(m)(n) $n = deposit\_elemental\_count(m)$

Pathways:	1x, a9	
number_of_pathways	1x, i3	valid range = the number of
		pathways specified in the plant
		model file

Pathway 1:	1x, a10	
pathway_detail(1)	1x, i3	valid range = 0 to 1 inclusive
		0 = no detailed output printed
		1 = detailed output printed

pathway_decay(1)	1x, i3	valid range = 0 to 1 inclusive

0 = no decay chain processing
1 = decay chain processing

piping_aerosol_model(1) 1x, i3 valid range = 0 to 2 inclusive
0 = no aerosol removal
1 = user-specified decontamination factors
2 = decontamination factors calculated using a model (no model is available at this time)

These lines will be included if and only if the user-specified (*piping_aerosol_model = 1*) decontamination factors are used.

piping_aerosol_count(1) 1x, i3 valid range = 1 to 25 inclusive

piping_aerosol_time(1)(1) units = hours
piping_aerosol_df(1)(1) units = per second
piping_aerosol_flow(1)(1) 3(1x, e11.4) units = cubic meters per second
these three variables appear on the same line in the file

piping_aerosol_time(1)(n)
piping_aerosol_df(1)(n)
piping_aerosol_flow(1)(n) n = *piping_aerosol_count(1)*

End of user-specified decontamination factors.

piping_elemental_model(1) 1x, i3 valid range = 0 to 2 inclusive
0 = no elemental iodine removal
1 = user-specified elemental iodine decontamination factors
2 = elemental iodine decontamination factors calculated using a model (no model is available at this time)

These lines will be included if and only if the user-specified (*piping_elemental_model = 1*) decontamination factors are used.

piping_elemental_count(1) 1x, i3 valid range = 1 to 25 inclusive

piping_elemental_time(1)(1) units = hours
piping_elemental_df(1)(1) units = per second
piping_elemental_flow(1)(1) 3(1x, e11.4) units = cubic meters per second
these three variables appear on the same line in the file

piping_elemental_time(1)(n)
piping_elemental_df(1)(n)
piping_elemental_flow(1)(n)   n = *piping_elemental_count(1)*

End of user-specified decontamination factors.

piping_organic_model(1)	1x, i3	valid range = 0 to 2 inclusive 0 = no aerosol removal 1 = user-specified aerosol decontamination factors 2 = aerosol decontamination factors calculated using a model (no model is available at this time)

These lines will be included if and only if the user-specified (*piping_elemental_model* = 1) decontamination factors are used.

piping_organic_count(1)	1x, i3	valid range = 1 to 25 inclusive
piping_organic_time(1)(1) *piping_organic_df(1)(1)* *piping_organic_flow(1)(1)*	3(1x, e11.4)	units = hours units = per second units = cubic meters per second these three variables appear on the same line in the file

piping_organic_time(1)(n)
piping_organic_df(1)(n)
piping_organic_flow(1)(n)   n = *piping_organic_count(1)*

End of user-specified decontamination factors.

p_filter_norm_flow_rate(1)	1x, e11.4	units = per second
p_filter_eff_count(1)	1x, i3	valid range = 0 to 25 inclusive 0 = no filter action 1-25 = number of filter efficiencies
p_filter_aerosol_eff(1)(1)		units = percent valid range = 0.0 to 100.0 inclusive
p_filter_elemental_eff(1)(1)		units = percent valid range = 0.0 to 100.0 inclusive
p_filter_organic_eff(1)(1)	3(1x, e11.4)	units = percent valid range = 0.0 to 100.0 inclusive these three variables appear on the same line in the file

p_filter_aerosol_eff(1)(n)
p_filter_elemental_eff(1)(n)
p_filter_organic_eff(1)(n)   n = filter_eff_count(1)

sp_aerosol_model(1)	1x, i3	valid range = 0 to 2 inclusive 0 = no aerosol removal 1 = user-specified decontamination factors 2 = decontamination factors calculated using a model (no model is available at this time)

These lines will be included if and only if the user-specified (sp_aerosol_model(1) = 1) decontamination factors are used.

sp_initial_volume(1)	1x, e11.4	units = cubic meters valid range ≥ 0.0 0.0 = no suppression pool
sp_aerosol_count(1)	1x, i3	valid range = 1 to 25 inclusive
sp_aerosol_time(1)(1) sp_aerosol_df(1)(1)	2(1x, e11.4)	units = hours valid range = 0.0 to 1.0 these two variables appear on the same line in the file

sp_aerosol_time(1)(n)
sp_aerosol_df(1)(n)   n = sp_aerosol_count(1)

End of user-specified decontamination factors.

sp_elemental_model(1)	1x, i3	valid range = 0 to 2 inclusive 0 = no elemental iodine removal 1 = user-specified decontamination factors 2 = decontamination factors calculated using a model (no model is available at this time)

These lines will be included if and only if user-specified (sp_elemental_model(1) = 1) decontamination factors are used.

sp_elemental_count(1)	1x, i3	valid range = 1 to 25 inclusive
sp_elemental_time(1)(1) sp_elemental_df(1)(1)	2(1x, e11.4)	units = hours valid range = 0.0 to 1.0 these two variables appear on the same line in the file

sp_elemental_time(1)(n)
sp_elemental_df(1)(n)   n = *sp_elemental_df_count*

End of user-specified decontamination factors.

sp_organic_model(1)	1x, i3	valid range = 0 to 2 inclusive 0 = no organic iodine removal 1 = user-specified decontamination factors 2 = decontamination factors calculated using a model (no model is available at this time)

These lines will be included if and only if user-specified (*sp_organic_model(1)* = 1) decontamination factors are used.

sp_organic_count(1)	1x, i3	valid range = 0 to 25 inclusive 0 = no organic iodine decontamination 1-25 = number of decontamination factors

sp_organic_time(1)(1)		units = hours
sp_organic_df(1)(1)	2(1x, e11.4)	valid range = 0.0 to 1.0 these two variables appear on the same line in the file

sp_organic_time(1)(n)
sp_organic_df(1)(n)   n = *sp_organic_count(1)*

End of user-specified decontamination factors.

sp_volatilization_model(1)	1x, i3	0 = no iodine volatilization

convection_model(1)	1x, i3	valid range = 0 to 2 inclusive 0 = no natural convection 1 = user-specified normalized flow rates 2 = normalized flow rates calculated using a model (no model is available at this time)

These lines will be included if and only if the user-specified (*convection_model(1)* = 1) decontamination factors are used.

convection_count(1)	1x, i3	valid range = 1 to 25 inclusive
convection_norm_flow_rate(1)(1)	1x, e11.4	units = per second
convection_norm_flow_rate(1)(n)		n = *convection_count(1)*

End of user-specified normalized flow rates.

water_leakage_model(1)	1x, i3	0 = no water leakage

End of user-specified normalized flow rates.

Pathway m:

pathway_detail(m)

pathway_decay(m)

water_leakage_rate(m)(n)		m = *number_of_pathways*
		n = *water_leakage_count(m)*
Dose Locations:	1x, a15	
number_of_locations	1x, i3	valid range = 0 to 10
Location 1:	1x, a11	
location_name(1)	1x, a40	valid range = printable ASCII characters from 32 to 126 inclusive
compartment_number(1)	1x, i3	valid range = 1 to n inclusive the number of the compartment that the location is in.
pathway_count(1)	1x, i3	valid range = 0 to 10
pathway_number(1)(1)	1x, i3	valid range = 1 to 100
pathway_exp_time(1)(1)	1x, e11.4	units = hours
pathway_xq_model(1)(1)	1x, i3	valid range = 0 to 2 inclusive 0 = X/Q is a constant 1.0 1 = user-specified X/Q 2 = X/Q calculated using a model (no model is available at this time)

These lines will be included if and only if the user-specified (*pathway_xq_model(1)(1)* = 1) X/Q factors are used.

pathway_xq_count(1)(1)   1x, i3   valid range = 1 to 25

pathway_xq_time(1)(1)(1)   units = hours
pathway_xq(1)(1)(1)   2(1x, e11.4)   units = seconds per cubic meters
                                                                     these two variables appear on the
                                                                     same line in the file

pathway_xq_time(1)(1)(n)
pathway_xq(1)(1)(n)   n = *pathway_xq_count(1)(1)*

End of user-specified X/Q factors.

pathway_number(1)(m)

pathway_exp_time(1)(m)

pathway_xq_model(1)(m)

pathway_xq(1)(m)(1)

pathway_xq(1)(m)(n)   m = *pathway_count(1)*
                                                                     n = *pathway_xq_count(1)(m)*

Location ℓ:

location_name(ℓ)

compartment_number(ℓ)

pathway_xq_model(ℓ)(m)

pathway_xq(ℓ)(m)(1)

pathway_xq(ℓ)(m)(n)   l = *number_of_locations*
                                                                     m = *pathway_count(ℓ)*
                                                                     n = *pathway_xq_count(ℓ)(m)*

End of Scenario File   1x, a32

1.4.3.5.1 Acceptance Test Case #24 SDF File

```
Scenario Description Name:

Plant Model Filename:
ACCEPT\TEST24.SDF
Source Term:
1
DEFAULTS\FGR60.NIS  DEFAULTS\FGR60.INP  2
DEFAULTS\PWR_DBA.RFT
0.0000E+00
0.9500E+00  0.4850E-01  0.1500E-02  0.1000E+01
Overlying Pool:
0
0.0000E+00
0
0
0
0
Compartments:
5
Compartment  1:
0
0
2
0.0000E+00
0.1000E+01
0.5000E+02
2
0.0000E+00  0.3940E-01  0.8500E+02
0.3000E+01  0.0000E+00  0.8500E+02
1
0.0000E+00
5
0.0000E+00  0.1500E+01
0.5000E+00  0.1200E+02
0.1800E+01  0.5000E+01
0.2000E+01  0.2000E+01
0.8000E+01  0.4000E+00
1
0.0000E+00
0
0
0
1
0
0

Compartment  2:
0
0
0
0
0
0
1
2
0.0000E+00  0.0000E+00  0.1500E+00
0.7200E+03  0.1500E+00
0

Compartment  3:
0
0
0
0
0
0
0
0

Compartment  4:
0
0
0
0
0
0
0
0
0

Compartment  5:
1
0
0
0
0
1
2
0.4000E+04
0.0000E+00  0.9900E+02  0.9500E+02
0.7200E+03  0.9900E+02  0.9500E+02
0
```

```
0
Pathways:
    10
Pathway    1:
0
0
0
          0
0
0
0
1
5
0.0000E+00      0.1053E+04
0.1667E+00      0.4056E+04
0.5000E+00      0.4425E+04
0.1175E+01      0.2951E+04
0.1800E+01      0.1053E+04
0
Pathway    2:
0
0
0
0
0
0
0
1
2
0.0000E+00      0.4500E+00
0.2400E+02      0.2250E+00
0
Pathway    3:
0
0
0
0
0
0
0

0
1
2
0.0000E+00      0.5000E-01
0.2400E+02      0.2500E-01
0
Pathway    4:
0
0
0
0
0
0
0
1
5
0.0000E+00      0.4800E+04
0.1667E+00      0.1845E+05
```

```
                                      0.5000E+00    0.2016E+05
                                      0.1175E+01    0.1344E+05
                                      0.1800E+01    0.4800E+04
                                      0
                         Pathway    5:
                                      0
                                      0
                                      0
                                      0
                                      0
                                      0
                                      0
                                      1
                                      2
                                      0.0000E+00    0.4500E+00
                                      0.2400E+02    0.2250E+00
                                      0
                         Pathway    6:
                                      0
                                      0
                                      0
                                      0
                                      0
                                      0
                                      0
                                      0
                                      1
                                      2
                                      0.0000E+00    0.5000E-01
                                      0.2400E+02    0.2500E-01
                                      0
                         Pathway    7:
                                      0
                                      0
                                      1
                                      3
                                      0.0000E+00    0.1000E+03    0.0000E+00
                                      0.2780E-01    0.1000E+03    0.1400E+05
                                      0.2778E+00    0.1000E+03    0.1000E+04
                                      1
                                      3
                                      0.0000E+00    0.1000E+01    0.0000E+00
                                      0.2780E-01    0.1000E+01    0.1400E+05
                                      0.2778E+00    0.1000E+01    0.1000E+04
                                      0
                                      0
                                      0
                                      0
                                      0
                                      0
                                      0
                         Pathway    8:
                                      0
                                      0
                                      0
                                      1
                                      2
                                      0.2000E+04
                                      0.0000E+00    0.9900E+02    0.9500E+02
                                      0.7200E+03    0.9900E+02    0.9500E+02
                                      0
                                      0
                                      0
                                      0
                                      0
                                      0
                                      0
                         Pathway    9:
                                      0
                                      0
                                      0
                                      1
                                      2
                                      0.1000E+02
                                      0.0000E+00    0.0000E+00    0.0000E+00
                                      0.7200E+03    0.0000E+00    0.0000E+00
                                      0
                                      0
                                      0
                                      0
                                      0
                                      0
                                      0
                         Pathway   10:
```

```
0
0
0
0
0
1
0.2010E+04
2
0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.7200E+03   0.0000E+00   0.0000E+00   0.0000E+00
0
0
0
0
Dose Locations:
3
Location  1:
Exclusion Area Boundary
4
1
2
0.0000E+00   0.1000E-02
0.2000E+01   0.0000E+00
1
3
0.0000E+00   0.3470E-03
0.8000E+01   0.1750E-03
0.2400E+02   0.2320E-03
0
Location  2:
Low Population Zone
4
1
4
0.0000E+00   0.1350E-03
0.8000E+01   0.1000E-03
0.2400E+02   0.5400E-04
0.9600E+02   0.2200E-04
1
3
0.0000E+00   0.3470E-03
0.8000E+01   0.1750E-03
0.2400E+02   0.2320E-03
0
Location  3:
Control Room
```

```
5
0
1
2
0.0000E+00   0.3470E-03
0.7200E+03   0.0000E+00
1
4
0.0000E+00   0.1000E+01
0.2400E+02   0.6000E+00
0.9600E+02   0.4000E+00
0.7200E+03   0.0000E+00
Effective Volume Location:
1
5
0.0000E+00   0.2200E-02
0.2000E+01   0.1500E-02
0.8000E+01   0.1300E-02
0.2400E+02   0.8400E-03
0.9600E+02   0.4800E-03
Simulation Parameters:
5
0.0000E+00   0.5000E-01
0.3000E+01   0.2500E+00
0.8000E+01   0.1000E+01
0.2400E+02   0.4000E+01
0.7200E+03   0.0000E+00
Output Filename:
ACCEPT\TEST24.TXT
1
1
1
0
0
End of Scenario File
```

1.5 Output Description

The software output is of three types. The first type is summary output and is always generated by the software. It consists of a brief description of the scenario that was being analyzed, as well as the time-dependent, whole-body, thyroid, and total effective dose equivalent (TEDE) doses resulting from releases during user-specified time periods. This is followed by summary tables for the whole-body TEDE and thyroid dose, as well as the ^{131}I concentrations at all user-selected locations. This information may be browsed at any time via the user interface. A hard copy may be generated at any time during such an examination. Alternatively, the summary output file can be written to an ASCII text file which can be imported into a word processor or spreadsheet.

The second type of output is detailed output that is intended to be used to record, as functions of time, the intermediate results used in the calculations. The start and end times to be used for generating these results are under the control of the user and typically include the entire accident progression. The specification of which results to store is under the control of the user but all of these selections must be made prior to execution of the scenario. The detailed output is generated in ASCII text format and written to the output file. A list of the intermediate results that can be generated is:

1. the total radioactivity, as well as the number of radioactive and stable atoms in a compartment (a "compartment" in this section refers not just to the enclosed atmosphere, but to all locations in the volume and its surfaces that can hold radioactive material, for example, the surfaces, filters, and pools associated with each compartment defined in the plant model);
2. the number of atoms and radioactivity of each fission product in a compartment; and
3. the transport rate of total radioactivity, as well as the number of radioactive and stable atoms passed to the environment.

The third type of output is primarily used by the developers to debug a subroutine or model. Within the logic for each subroutine are embedded print statements that are controlled by a variable named Level XXX where XXX is the subroutine name. The value of this variable indicates the quantity of additional information required; a 0 = no additional and a 9 = all input and calculated values. Intermediate values will get intermediate prints. These variables can be initialized by the user in data set FLAG.DAT, as discussed in Section 4.2.3.

1.5.1 Sample Output

Typical output is shown on the following pages and is described here.

In the beginning of the output is an annotated list of the input. In the example provided, the full listing of the input takes several pages because a detailed problem was chosen. In most cases, the user will specify fewer volumes with less flow paths, resulting in a shorter listing.

After the header *File Information*, the output lists the external files the case will use for background information such as dose conversion factors and to store input and output results.

After the header *Plant Description*, the output details the plant as described by the user. This section is also displayed in screen 1800 if chosen by the user during the input mode. In this example the user has described 5 volumes; the first one contains the source from the reactor coolant system. Each path to other compartments is listed, as well as the flow direction. There is flow in both directions between volumes 1 and 2 as indicated by the pathway to and pathway from lines. For each volume, its size and any active removal devices, for example, sprays or recirculating filters, are also noted. With this information a plant is described that can be used for a variety of accident scenarios.

After the header *Scenario Description*, the output details the scenario chosen for this example. The first part gives the information for generating the source term, such as plant power, the iodine chemical form, and the decay and daughtering selections. The next part details information about each compartment. For example, in compartment 1 the user selected the Powers spray model; hence the input from screen 2311B is edited. In compartment 5, the control room, the capabilities of the recirculating filter are edited. The third part details the pathway data. In this part the input for each pathway is detailed. For example, the flow between compartments 1 and 2 is given under pathway 1 for flow from 1 to 2 and under pathway 4 for flow from 2 to 1. In this example, volume 1 is the sprayed region of the containment and volume 2 is the unsprayed region, hence the mixing flows. Pathway number 8 is between the environment and the control room. Note that a filter exists on this path with the capability of removing most aerosols, elemental iodines, and organic iodines. The fourth part of this section details the dose location information as controlled from screens associated with screen 2500. In this part, the X/Q, breathing rate, and occupancy information are edited. The fifth section details the time-step limitation information the user has selected; in this case a 900-s (0.25-hr) limit is imposed between the start of the accident and 8 hr.

After the header *Dose, Detailed Model and Detailed Inventory Output*, the full output is presented. In this case only the first step dose results and the last step detailed dose and mass distribution results are shown. The user has control over the quantity of output, most noticeably by requesting detailed output on screen 2300. Without this selection, only the dose results would be edited. In this example, the user has selected detailed mass distributions for several volumes, the environment and the control room. The nuclide distributions are given for the volume in a variety of units. These are also summed by chemical group following the nuclide detailed output. Note that for the environment compartment, the nuclide release rates are also given. After the volume or compartment information is detailed, all pathways linked to that compartment are also detailed for each chemical group mass. Thus one can see the mass retained by the filter between the environment and the control room and between the annulus and the environment. Following the nuclide inventory in the control room are the chemical group masses in the control room and in the recirculating filter, as well as the masses in the pathways connected to the control room. This is followed by the dose and ^{131}I concentration summary tables.

1.5.2 Sample Output File

```
#####################################################################
######
          RADTRAD Version 2.12  06/12/97 21:45:47.70
#####################################################################
######
#####################################################################
######
#####################################################################
######

#####################################################################
######              File information
#####################################################################
######
Plant filename           = accept\test24a.pmf
Inventory filename       = DEFAULTS\PWR_DEF.NIF
Scenario filename        = accept\test24a.sdf
Release filename         = DEFAULTS\PWR_DBAA.RFT
Dose conversion filename = DEFAULTS\FGR60.INP
#####################################################################
######
#####################################################################
######              Plant Description
#####################################################################
######
#####################################################################
######

Number of Nuclides = 60

Inventory Power    = 0.1000E+01 MWth
Plant Power Level  = 0.3992E+04 MWth

Number of compartments    = 5

Compartment information

Compartment number 1    (Source term compartment)
Name: Sprayed Region
Compartment volume = 0.2740E+07 (Cubic feet)
Removal devices within compartment:
     Spray(s)
Pathways into and out of compartment  1
     Pathway to compartment number   2: Sprayed to Unsprayed
     Pathway to compartment number   3: Sprayed to Annulus
     Pathway to compartment number   4: Sprayed to Environment
     Pathway from compartment number 2: Unsprayed to Sprayed

Compartment number 2
Name: Unsprayed Region
Compartment volume = 0.6011E+06 (Cubic feet)
Removal devices within compartment:
     Deposition
Pathways into and out of compartment  2
     Pathway to compartment number   1: Unsprayed to Sprayed
     Pathway to compartment number   3: Unsprayed to Annulus
     Pathway to compartment number   4: Unsprayed to Environment
     Pathway from compartment number 1: Sprayed to Unsprayed

Compartment number 3
Name: Annulus
Compartment volume =  0.6162E+06 (Cubic feet)
Pathways into and out of compartment  3
     Pathway to compartment number   4: Annulus to Environment
     Pathway from compartment number 1: Sprayed to Annulus
     Pathway from compartment number 2: Unsprayed to Annulus

Compartment number  4
Name: Environment
Pathways into and out of compartment  4
     Pathway to compartment number   5: Filter 3--Environment to
CR
     Pathway to compartment number   5: Unfiltered--Environment to
CR
     Pathway from compartment number 1: Sprayed to Environment
     Pathway from compartment number 2: Unsprayed to Environment
     Pathway from compartment number 3: Annulus to Environment
     Pathway from compartment number 5: Exhaust from CR to
Environment

Compartment number  5
Name: Control Room
Compartment volume =  0.6731E+05 (Cubic feet)
Removal devices within compartment:
     Filter(s)
Pathways into and out of compartment  5
     Pathway to compartment number   4: Exhaust from CR to
Environment
     Pathway from compartment number 4: Filter 3--Environment to
CR
     Pathway from compartment number 4: Unfiltered--Environment to
CR

Total number of pathways = 10

#########################################################################
#######
#########################################################               Scenario Description
#######
#########################################################################
#######
Iodine fractions
    Aerosol     =   0.9500E+00
    Elemental   =   0.4850E-01
    Organic     =   0.1500E-02

COMPARTMENT DATA

Compartment number   1: Sprayed Region

    Sprays:  Aerosol Removal Data

       alpha = 0.1000E+01
       percentile = 50
```

```
Time (hr)          Flux (cf*ft^-2*min^-1)    Height (ft)
0.0000E+00         0.3940E-01                0.8500E+02
0.3000E+01         0.0000E+00                0.8500E+02
```

Sprays: Elemental Removal Data
```
Time (hr)     DF (hr^-1)
0.0000E+00    0.1500E+01
0.5000E+00    0.1200E+02
0.1800E+01    0.5000E+01
0.2000E+01    0.2000E+01
0.8000E+01    0.4000E+00
```

Natural Deposition: Aerosol data
```
Time (hr)     DF (hr^-1)
0.0000E+00    0.1500E+00
0.7200E+03    0.1500E+00
```

Compartment number   2: Unsprayed Region

Compartment number   3: Annulus

Compartment number   4: Environment

Compartment number   5: Control Room

Compartment Filter Data

Flow rate = 0.4000E+04 (cfm)

Time (hr)	Filter Efficiencies (%)		
	Aerosol	Elemental	Organic
0.0000E+00	0.9900E+02	0.9500E+02	0.9500E+02
0.7200E+03	0.9900E+02	0.9500E+02	0.9500E+02

PATHWAY DATA

Pathway number   1: Sprayed to Unsprayed

Convection Data
```
Time (hr)     Flow Rate (% / day)
0.0000E+00    0.1053E+04
0.1667E+00    0.4056E+04
0.5000E+00    0.4425E+04
0.1175E+01    0.2951E+04
0.1800E+01    0.1053E+04
```

Pathway number   2: Sprayed to Annulus

Convection Data
```
Time (hr)     Flow Rate (% / day)
0.0000E+00    0.4500E+00
0.2400E+02    0.2250E+00
```

Pathway number   3: Sprayed to Environment

Convection Data
```
Time (hr)     Flow Rate (% / day)
0.0000E+00    0.5000E-01
0.2400E+02    0.2500E-01
```

Pathway number   4: Unsprayed to Sprayed

Convection Data
```
Time (hr)     Flow Rate (% / day)
0.0000E+00    0.4800E+04
0.1667E+00    0.1845E+05
0.5000E+00    0.2016E+05
0.1175E+01    0.1344E+05
0.1800E+01    0.4800E+04
```

Pathway number   5: Unsprayed to Annulus

Convection Data
```
Time (hr)     Flow Rate (% / day)
0.0000E+00    0.4500E+00
0.2400E+02    0.2250E+00
```

Pathway number   6: Unsprayed to Environment

Convection Data
```
Time (hr)     Flow Rate (% / day)
0.0000E+00    0.5000E-01
0.2400E+02    0.2500E-01
```

Pathway number   7: Annulus to Environment

Piping: Removal Data

Time (hr)	Flow Rate (cfm)	DF (s^-1)		
		Aerosol	Elemental	Organic
0.0000E+00	0.2118E+00	0.3600E+06	0.2778E-03	0.2778E-03
0.2780E-01	0.1400E+05	0.3600E+06	0.2778E-03	0.2778E-03
0.2778E+00	0.1000E+04	0.3600E+06	0.2778E-03	0.2778E-03

Pathway number   8: Filter 3--Environment to CR

Pathway Filter: Removal Data

Filter flow rate = 0.2000E+04 (cfm)

Time (hr)	Filter efficiency (%)		
	Aerosol	Elemental	Organic
0.0000E+00	0.9900E+02	0.9500E+02	0.9500E+02
0.7200E+03	0.9900E+02	0.9500E+02	0.9500E+02

Pathway number   9: Unfiltered--Environment to CR

Pathway Filter: Removal Data

Filter flow rate = 0.1000E+02 (cfm)

```
                    Filter efficiency (%)
Time (hr)      Aerosol      Elemental      Organic
0.0000E+00    0.0000E+00   0.0000E+00    0.0000E+00
0.7200E+03    0.0000E+00   0.0000E+00    0.0000E+00

Pathway number 10: Exhaust from CR to Environment

Pathway Filter: Removal Data

Filter flow rate =  0.2010E+04 (cfm)

                    Filter efficiency (%)
Time (hr)      Aerosol      Elemental      Organic
0.0000E+00    0.0000E+00   0.0000E+00    0.0000E+00
0.7200E+03    0.0000E+00   0.0000E+00    0.0000E+00

LOCATION DATA
Location Exclusion Area Boundary       is in compartment    4

Location X/Q Data
Time (hr)      X/Q (s * m^-3)
0.0000E+00    0.1000E-02
0.2000E+01    0.0000E+00

Location Breathing Rate Data
Time (hr)      Breathing Rate (m^3 * sec^-1)
0.0000E+00    0.3470E-03
0.8000E+01    0.1750E-03
0.2400E+02    0.2320E-03
Location Low Population zone    is in compartment    4

Location X/Q Data
Time (hr)      X/Q (s * m^-3)
0.0000E+00    0.1350E-03
0.8000E+01    0.1000E-03
0.2400E+02    0.5400E-04
0.9600E+02    0.2200E-04

Location Breathing Rate Data
Time (hr)      Breathing Rate (m^3 * sec^-1)
0.0000E+00    0.3470E-03
0.8000E+01    0.1750E-03
0.2400E+02    0.2320E-03
Location Control Room     is in compartment    5

Location Breathing Rate Data
Time (hr)      Breathing Rate (m^3 * sec^-1)
0.0000E+00    0.3470E-03
0.7200E+03    0.0000E+00

Location Occupancy Factor Data
Time (hr)      Occupancy Factor
0.0000E+00    0.1000E+01
0.2400E+02    0.6000E+00
0.9600E+02    0.4000E+00
0.7200E+03    0.0000E+00

USER SPECIFIED TIME STEP DATA - SUPPLEMENTAL TIME STEPS
```

```
Time            Time step
0.0000E+00     0.5000E-01
0.3000E+01     0.2500E+00
0.8000E+01     0.1000E+01
0.2400E+02     0.4000E+01
0.7200E+03     0.0000E+00

######################################################
######    Dose, Detailed model and Detailed Inventory Output
######################################################
#######
Exclusion Area Boundary Doses:

Time (h) =   0.0278      Whole Body     Thyroid      TEDE
Delta dose (rem)         0.2437E-03    0.4064E-01   0.1758E-02
Accumulated dose (rem)   0.2437E-03    0.4064E-01   0.1758E-02

Low Population Zone Doses:

Time (h) =   0.0278      Whole Body     Thyroid      TEDE
Delta dose (rem)         0.3290E-04    0.5487E-02   0.2373E-03
Accumulated dose (rem)   0.3290E-04    0.5487E-02   0.2373E-03

Control Room Doses:

Time (h) =   0.0278      Whole Body     Thyroid      TEDE
Delta dose (rem)         0.8335E-07    0.3609E-04   0.1403E-05
Accumulated dose (rem)   0.8335E-07    0.3609E-04   0.1403E-05

Environment Atmosphere Nuclide Inventory:

Time (h) =   0.0278      Atoms         kg           Ci              Bq
Kr-85         0.1138E+17    0.1606E-08   0.6299E-03
0.2331E+08
Kr-85m        0.2540E+14    0.3585E-11   0.2951E-01
0.1092E+10
Kr-87         0.1318E+14    0.1904E-11   0.5393E-01
0.1995E+10
Kr-88         0.3980E+14    0.5815E-11   0.7292E-01
0.2698E+10
Rb-86         0.3835E+13    0.5477E-12   0.4457E-04
0.1649E+07
I-131         0.2815E+16    0.6123E-09   0.7591E-01
0.2809E+10
I-132         0.4944E+14    0.1084E-10   0.1119E+00
0.4139E+10
I-133         0.6415E+15    0.1417E-09   0.1605E+00
0.5938E+10
I-134         0.2967E+14    0.6602E-11   0.1761E+00
0.6517E+10
I-135         0.1922E+15    0.4309E-10   0.1513E+00
0.5599E+10
Xe-133        0.4176E+16    0.9223E-09   0.1726E+00
0.6388E+10
Xe-135        0.5659E+14    0.1269E-10   0.3240E-01
0.1199E+10
```

Filter 3—Environment to CR Transport Group Inventory:

	Pathway Filter
Time (h) = 0.0278	
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.5736E+16
Organic I (atoms)	0.1799E+15
Aerosols (kg)	0.2316E-05

Unfiltered—Environment to CR Transport Group Inventory:

	Pathway Filter
Time (h) = 0.0278	
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Exhaust from CR to Environment Transport Group Inventory:

	Pathway Filter
Time (h) = 0.0278	
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Control Room Atmosphere Nuclide Inventory:

Time (h) = 0.0278

Nuclide	Bq	Atoms	kg	Ci
Kr-85	0.4784E+05	0.2335E+14	0.3296E-11	0.1293E-05
Kr-85m	0.2241E+07	0.5214E+11	0.7360E-14	0.6057E-04
Kr-87	0.4096E+07	0.2705E+11	0.3908E-14	0.1107E-03
Kr-88	0.5538E+07	0.8169E+11	0.1194E-13	0.1497E-03
Rb-86	0.4888E+02	0.1137E+09	0.1623E-16	0.1321E-08
I-131	0.9506E+05	0.9527E+11	0.2072E-13	0.2569E-05
I-132	0.1401E+06	0.1673E+10	0.3668E-15	0.3786E-05
I-133	0.2010E+06	0.2171E+11	0.4795E-14	0.5432E-05
I-134	0.2206E+06	0.1004E+10	0.2234E-15	0.5961E-05
I-135	0.1895E+06	0.6505E+10	0.1458E-14	0.5121E-05
Xe-133	0.1311E+08	0.8573E+13	0.1893E-11	0.3544E-03
Xe-135	0.2460E+07	0.1162E+12	0.2604E-13	0.6650E-04
Cs-134	0.1119E+05	0.1050E+13	0.2337E-12	0.3024E-06

Environment Atmosphere Nuclide Release Rates:

Time (h) = 0.0278

Nuclide	Bq/s	Atoms/s	kg/s	Ci/s
Kr-85	0.2329E+06	0.1137E+15	0.1604E-10	0.6294E-05
Kr-85m	0.1091E+08	0.2538E+12	0.3583E-13	0.2948E-03
Kr-87	0.1994E+08	0.1317E+12	0.1902E-13	0.5388E-03
Kr-88	0.2696E+08	0.3977E+12	0.5811E-13	0.7286E-03
Rb-86	0.1648E+05	0.3832E+11	0.5473E-14	0.4453E-06
I-131	0.2807E+08	0.2813E+14	0.6118E-11	0.7585E-03
I-132	0.4137E+08	0.4940E+12	0.1083E-12	0.1118E-02
I-133	0.5935E+08	0.6410E+13	0.1416E-11	0.1604E-02
I-134	0.6512E+08	0.2965E+12	0.6597E-13	0.1760E-02
I-135	0.5594E+08	0.1921E+13	0.4305E-12	0.1512E-02
Xe-133	0.6383E+08	0.4173E+14	0.9216E-11	0.1725E-02
Xe-135	0.1198E+09	0.5654E+12	0.1268E-12	0.3237E-02
Cs-134	0.3775E+09	0.3544E+17	0.7886E-08	0.1020E-01
Cs-136	0.1149E+09	0.1875E+15	0.4235E-10	0.3104E-02
Cs-137	0.2111E+09	0.2883E+18	0.6559E-07	0.5705E-02

Environment Transport Group Inventory:

Time (h) = 0.0278

	Present Release	Release Rate/s	Total Release
Noble gases (atoms)	0.1569E+17	0.1567E+15	0.1569E+17
Elemental I (atoms)	0.1917E+15	0.1916E+13	0.1917E+15
Organic I (atoms)	0.6013E+13	0.6008E+11	0.6013E+13
Aerosols (kg)	0.7429E-07	0.7423E-09	0.7429E-07

Annulus to Environment Transport Group Inventory:

Time (h) = 0.0278

	Pipe Walls
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.2638E+02
Organic I (atoms)	0.8273E+00
Aerosols (kg)	0.1265E-12

Cs-136   0.3404E+04   0.5559E+10   0.1255E-14   0.9201E-07
Cs-137   0.6257E+04   0.8545E+13   0.1944E-11   0.1691E-06

Control Room Transport Group Inventory:

Time (h) = 0.0278	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	0.3220E+14	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.2088E+11	0.0000E+00	0.0000E+00
Organic I (atoms)	0.6549E+09	0.0000E+00	0.0000E+00
Aerosols (kg)	0.2202E-11	0.0000E+00	0.0000E+00

Time (h) = 0.0278	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.6554E+09
Organic I (atoms)	0.0000E+00	0.2056E+08
Aerosols (kg)	0.0000E+00	0.7203E-13

Filter 3--Environment to CR Transport Group Inventory:

Time (h) = 0.0278	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.5736E+16
Organic I (atoms)	0.1799E+15
Aerosols (kg)	0.2316E-05

Unfiltered--Environment to CR Transport Group Inventory:

Time (h) = 0.0278	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Exhaust from CR to Environment Transport Group Inventory:

Time (h) = 0.0278	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

*** Intermediate time steps not edited ***

Exclusion Area Boundary Doses:

Time (h) = 720.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	0.0000E+00		0.0000E+00
Accumulated dose (rem)	0.1663E+01	0.6858E+02	0.4539E+01

Low Population Zone Doses:

Time (h) = 720.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	0.6554E+02	0.2970E+02	0.6748E+02
Accumulated dose (rem)	0.1038E+03	0.6043E+02	0.1058E+03

Control Room Doses:

Time (h) = 720.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	0.2119E+02	0.7350E+01	0.2143E+02
Accumulated dose (rem)	0.3573E+02	0.1429E+02	0.3619E+02

Environment Atmosphere Nuclide Inventory:

Time (h) = 720.0000	Bq	Atoms	kg	Ci
Co-58	0.1251E+08	0.1104E+15	0.1063E-10	0.3380E-03
Co-60	0.9568E+07	0.2296E+16	0.2288E-09	0.2586E-03
Kr-85	0.1802E+16	0.8796E+24	0.1242E+00	0.4871E+05
Kr-85m	0.8442E+17	0.1964E+22	0.2773E-03	0.2282E+07
Kr-87	0.1543E+18	0.1019E+22	0.1472E-03	0.4170E+07
Kr-88	0.2086E+18	0.3078E+22	0.4497E-03	0.5639E+07
Rb-86	0.7338E+08	0.1707E+15	0.2437E-10	0.1983E-02
Sr-89	0.1115E+11	0.7016E+17	0.1037E-07	0.3013E+00
Sr-90	0.6016E+09	0.7976E+18	0.1192E-06	0.1626E-01
Sr-91	0.1433E+11	0.7070E+15	0.1068E-09	0.3873E+00
Sr-92	0.1491E+11	0.2099E+15	0.3207E-10	0.4030E+00
Y-90	0.6455E+07	0.2146E+13	0.3207E-12	0.1745E-03
Y-91	0.1358E+09	0.9904E+15	0.1497E-09	0.3670E-02
Y-92	0.1497E+09	0.2752E+13	0.4204E-12	0.4045E-02
Y-93	0.1693E+09	0.8882E+13	0.1372E-11	0.4576E-02
Zr-95	0.1715E+09	0.1368E+16	0.2158E-09	0.4636E-02
Zr-97	0.1788E+09	0.1569E+14	0.2528E-11	0.4832E-02
Nb-95	0.1622E+09	0.7106E+15	0.1121E-09	0.4383E-02
Mo-99	0.2366E+10	0.8111E+15	0.1333E-09	0.6395E-01
Tc-99m	0.2042E+10	0.6386E+14	0.1050E-10	0.5520E-01

Environment Atmosphere Nuclide Release Rates:

Time (h) = 720.0000

Nuclide	Bq/s	Atoms/s	kg/s	Ci/s
Ru-103	0.1763E+10	0.8630E+16	0.1476E-08	0.4764E-01
Ru-105	0.1146E+10	0.2644E+14	0.4609E-11	0.3098E-01
Ru-106	0.4005E+09	0.1838E+17	0.3235E-08	0.1082E-01
Rh-105	0.7941E+09	0.1458E+15	0.2543E-10	0.2146E-01
Sb-127	0.2163E+10	0.1038E+16	0.2190E-09	0.5847E-01
Sb-129	0.7662E+10	0.1719E+15	0.3683E-10	0.2071E+00
Te-127	0.2089E+10	0.1014E+15	0.2139E-10	0.5646E-01
Te-127m	0.2766E+09	0.3758E+16	0.7925E-09	0.7476E-02
Te-129	0.7193E+10	0.4333E+14	0.9283E-11	0.1944E+00
Te-129m	0.1896E+10	0.7941E+16	0.1701E-08	0.5124E-01
Te-131m	0.3632E+10	0.5659E+15	0.1231E-09	0.9817E-01
Te-132	0.3616E+11	0.1468E+17	0.3219E-08	0.9772E+00
I-131	0.1402E+15	0.1405E+21	0.3057E-04	0.3790E+04
I-132	0.2067E+15	0.2469E+19	0.5411E-06	0.5585E+04
I-133	0.2965E+15	0.3203E+20	0.7074E-05	0.8013E+04
I-134	0.3254E+15	0.1481E+19	0.3296E-06	0.8794E+04
I-135	0.2795E+15	0.9597E+19	0.2151E-05	0.7555E+04
Xe-133	0.4940E+18	0.3230E+24	0.7132E-01	0.1335E+08
Xe-135	0.9269E+17	0.4376E+22	0.9810E-03	0.2505E+07
Cs-134	0.1680E+11	0.1577E+19	0.3509E-06	0.4541E+00
Cs-136	0.5111E+10	0.8346E+16	0.1885E-08	0.1381E+00
Cs-137	0.9393E+10	0.1283E+20	0.2919E-05	0.2539E+00
Ba-139	0.1950E+11	0.1396E+15	0.3222E-10	0.5271E+00
Ba-140	0.1930E+11	0.3065E+17	0.7125E-08	0.5216E+00
La-140	0.1972E+09	0.4125E+14	0.9590E-11	0.5330E-02
La-141	0.1809E+09	0.3692E+13	0.8644E-12	0.4888E-02
La-142	0.1744E+09	0.1396E+13	0.3292E-12	0.4713E-02
Ce-141	0.4386E+09	0.1777E+16	0.4160E-09	0.1185E-01
Ce-143	0.4264E+09	0.7308E+14	0.1735E-10	0.1152E-01
Ce-144	0.2643E+09	0.9365E+16	0.2239E-08	0.7142E-02
Pr-143	0.1675E+09	0.2831E+15	0.6722E-10	0.4526E-02
Nd-147	0.7490E+08	0.1025E+15	0.2502E-10	0.2024E-02
Np-239	0.5017E+10	0.1473E+16	0.5844E-09	0.1356E+00
Pu-238	0.2843E+06	0.1136E+16	0.4489E-09	0.7685E-05
Pu-239	0.6413E+05	0.7026E+17	0.2788E-07	0.1733E-05
Pu-240	0.8087E+05	0.2407E+17	0.9592E-08	0.2186E-05
Pu-241	0.1362E+08	0.8929E+16	0.3573E-08	0.3681E-03
Am-241	0.3598E+04	0.7080E+14	0.2834E-10	0.9725E-07
Cm-242	0.1377E+07	0.2795E+14	0.1123E-10	0.3722E-04
Cm-244	0.8058E+05	0.6644E+14	0.2692E-10	0.2178E-05
Co-58	0.5568E+01	0.4914E+08	0.4732E-17	0.1505E-09
Co-60	0.4259E+01	0.1022E+10	0.1018E-15	0.1151E-09
Kr-85	0.8023E+09	0.3916E+18	0.5527E-07	0.2168E-01
Kr-85m	0.3758E+11	0.8744E+15	0.1234E-09	0.1016E+01
Kr-87	0.6869E+11	0.4537E+15	0.6554E-10	0.1856E+01
Kr-88	0.9288E+11	0.1370E+16	0.2002E-09	0.2510E+01
Rb-86	0.3267E+02	0.7598E+08	0.1085E-16	0.8829E-09
Sr-89	0.4962E+04	0.3123E+11	0.4616E-14	0.1341E-06
Sr-90	0.2678E+03	0.3551E+12	0.5306E-13	0.7238E-08
Sr-91	0.6379E+04	0.3147E+09	0.4756E-16	0.1724E-06
Sr-92	0.6639E+04	0.9344E+08	0.1427E-16	0.1794E-06
Y-90	0.2873E+01	0.9551E+06	0.1427E-18	0.7766E-10
Y-91	0.6045E+02	0.4409E+09	0.6662E-16	0.1634E-08
Y-92	0.6663E+02	0.1225E+07	0.1871E-18	0.1801E-08
Y-93	0.7537E+02	0.3954E+07	0.6106E-18	0.2037E-08

Zr-95	0.7636E+02	0.6090E+09	0.9607E-16	0.2064E-08
Zr-97	0.7959E+02	0.6986E+07	0.1125E-17	0.2151E-08
Nb-95	0.7220E+02	0.3163E+09	0.4990E-16	0.1951E-08
Mo-99	0.1053E+04	0.3611E+09	0.5936E-16	0.2847E-07
Tc-99m	0.9092E+03	0.2843E+08	0.4673E-17	0.2457E-07
Ru-103	0.7847E+03	0.3842E+10	0.6571E-15	0.2121E-07
Ru-105	0.5103E+03	0.1177E+08	0.2052E-17	0.1379E-07
Ru-106	0.1783E+03	0.8183E+10	0.1440E-14	0.4819E-08
Rh-105	0.3535E+03	0.6492E+08	0.1132E-16	0.9555E-08
Sb-127	0.9631E+03	0.4622E+09	0.9747E-16	0.2603E-07
Sb-129	0.3411E+04	0.7653E+08	0.1639E-16	0.9219E-07
Te-127	0.9299E+03	0.4516E+08	0.9523E-17	0.2511E-07
Te-127m	0.1231E+03	0.1673E+10	0.3528E-15	0.3328E-08
Te-129	0.3202E+04	0.1929E+08	0.4132E-17	0.8654E-07
Te-129m	0.8440E+03	0.3535E+10	0.7572E-15	0.2281E-07
Te-131m	0.1617E+04	0.2519E+09	0.5480E-16	0.4370E-07
Te-132	0.1609E+05	0.6537E+10	0.1433E-14	0.4350E-06
I-131	0.6243E+08	0.6256E+14	0.1361E-10	0.1687E-02
I-132	0.9200E+08	0.1099E+13	0.2409E-12	0.2486E-02
I-133	0.1320E+09	0.1426E+14	0.3149E-11	0.3567E-02
I-134	0.1448E+09	0.6595E+12	0.1467E-12	0.3915E-02
I-135	0.1244E+09	0.4272E+13	0.9577E-12	0.3363E-02
Xe-133	0.2199E+12	0.1438E+18	0.3175E-07	0.5943E+01
Xe-135	0.4126E+11	0.1948E+16	0.4367E-09	0.1115E+01
Cs-134	0.7479E+04	0.7021E+12	0.1562E-12	0.2021E-06
Cs-136	0.2275E+04	0.3715E+10	0.8390E-15	0.6149E-07
Cs-137	0.4181E+04	0.5711E+13	0.1299E-11	0.1130E-06
Ba-139	0.8682E+04	0.6215E+08	0.1434E-16	0.2346E-06
Ba-140	0.8591E+04	0.1364E+11	0.3172E-14	0.2322E-06

La-140	0.8779E+02	0.1836E+08	0.4269E-17	0.2373E-08
La-141	0.8052E+02	0.1643E+07	0.3848E-18	0.2176E-08
La-142	0.7762E+02	0.6215E+06	0.1465E-18	0.2098E-08
Ce-141	0.1952E+03	0.7909E+09	0.1852E-15	0.5276E-08
Ce-143	0.1898E+03	0.3253E+08	0.7725E-17	0.5130E-08
Ce-144	0.1176E+03	0.4169E+10	0.9968E-15	0.3179E-08
Pr-143	0.7455E+02	0.1260E+09	0.2992E-16	0.2015E-08
Nd-147	0.3334E+02	0.4563E+08	0.1114E-16	0.9011E-09
Np-239	0.2233E+04	0.6556E+09	0.2602E-15	0.6036E-07
Pu-238	0.1266E+00	0.5056E+09	0.1998E-15	0.3421E-11
Pu-239	0.2855E-01	0.3128E+11	0.1241E-13	0.7716E-12
Pu-240	0.3600E-01	0.1071E+11	0.4270E-14	0.9730E-12
Pu-241	0.6063E+01	0.3975E+10	0.1591E-14	0.1639E-09
Am-241	0.1602E-02	0.3152E+08	0.1261E-16	0.4329E-13
Cm-242	0.6131E+00	0.1244E+08	0.5000E-17	0.1657E-10
Cm-244	0.3587E-01	0.2958E+08	0.1198E-16	0.9695E-12

Environment Transport Group Inventory:

	Present Release	Release Rate/s	Total Release
Time (h) = 720.0000			
Noble gases (atoms)	0.1213E+25	0.5400E+18	0.1432E+25
Elemental I (atoms)	0.2714E+15	0.1208E+09	0.3045E+19
Organic I (atoms)	0.1859E+21	0.8275E+14	0.2195E+21
Aerosols (kg)	0.1296E-03	0.5767E-10	0.5367E-02

Annulus to Environment Transport Group Inventory:

	Pipe Walls
Time (h) = 720.0000	
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.2192E+12
Organic I (atoms)	0.1578E+14
Aerosols (kg)	0.4387E-01

Filter 3--Environment to CR Transport Group Inventory:

	Pathway Filter
Time (h) = 720.0000	
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.4348E+22
Organic I (atoms)	0.1372E+25
Aerosols (kg)	0.7988E+01

Unfiltered--Environment to CR Transport Group Inventory:

Time (h) = 720.0000

	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Exhaust from CR to Environment Transport Group Inventory:

Time (h) = 720.0000

	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Control Room Atmosphere Nuclide Inventory:

Time (h) = 720.0000

	Atoms	kg	Ci	Bq
Co-58	0.2676E+00	0.2577E-25	0.8196E-18	0.3032E-07
Co-60	0.5567E+01	0.5546E-24	0.6270E-18	0.2320E-07
Kr-85	0.3467E+18	0.4894E-07	0.1920E-01	0.7105E+09
Kr-85m	0.7743E+15	0.1093E-09	0.8994E+00	0.3328E+11
Kr-87	0.4017E+15	0.5804E-10	0.1644E+01	0.6082E+11
Kr-88	0.1213E+16	0.1773E-09	0.2223E+01	0.8225E+11
Rb-86	0.4138E+00	0.5909E-25	0.4808E-17	0.1779E-06
Sr-89	0.1701E+03	0.2514E-22	0.7304E-15	0.2702E-04
Sr-90	0.1934E+04	0.2890E-21	0.3942E-16	0.1459E-05
Sr-91	0.1714E+01	0.2590E-24	0.9389E-15	0.3474E-04
Sr-92	0.5089E+00	0.7774E-25	0.9772E-15	0.3616E-04
Y-90	0.5202E-02	0.7774E-27	0.4230E-18	0.1565E-07
Y-91	0.2401E+01	0.3629E-24	0.8899E-17	0.3293E-06
Y-92	0.6672E-02	0.1019E-26	0.9808E-17	0.3629E-06
Y-93	0.2153E-01	0.3325E-26	0.1109E-16	0.4105E-06
Zr-95	0.3317E+01	0.5232E-24	0.1124E-16	0.4159E-06
Zr-97	0.3805E-01	0.6129E-26	0.1172E-16	0.4335E-06
Nb-95	0.1723E+01	0.2718E-24	0.1063E-16	0.3932E-05
Mo-99	0.1967E+01	0.3233E-24	0.1551E-15	0.5737E-05
Tc-99m	0.1548E+00	0.2545E-25	0.1338E-15	0.4952E-05
Ru-103	0.2092E+02	0.3579E-23	0.1155E-15	0.4274E-05
Ru-105	0.6409E-01	0.1117E-25	0.7512E-16	0.2779E-05
Ru-106	0.4456E+02	0.7844E-23	0.2624E-16	0.9710E-06
Rh-105	0.3536E+00	0.6165E-25	0.5204E-16	0.1925E-05
Sb-127	0.2517E+01	0.5308E-24	0.1418E-15	0.5245E-05
Sb-129	0.4168E+00	0.8928E-25	0.5021E-15	0.1858E-04
Te-127	0.2459E+00	0.5187E-25	0.1369E-15	0.5065E-05
Te-127m	0.9111E+01	0.1922E-23	0.1812E-16	0.6706E-06
Te-129	0.1051E+00	0.2251E-25	0.4713E-15	0.1744E-04
Te-129m	0.1925E+02	0.4124E-23	0.1242E-15	0.4597E-05
Te-131m	0.1372E+01	0.2985E-24	0.2380E-15	0.8806E-05
Te-132	0.3560E+02	0.7804E-23	0.2369E-14	0.8766E-04
I-131	0.1048E+13	0.2279E-12	0.2825E-04	0.1045E+07
I-132	0.1840E+11	0.4034E-14	0.4163E-04	0.1540E+07
I-133	0.2388E+12	0.5273E-13	0.5973E-04	0.2210E+07
I-134	0.1104E+11	0.2457E-14	0.6555E-04	0.2425E+07
I-135	0.7154E+11	0.1604E-13	0.5632E-04	0.2084E+07
Xe-133	0.1273E+18	0.2812E-07	0.5263E+01	0.1947E+12
Xe-135	0.1725E+16	0.3867E-09	0.9875E+00	0.3654E+11
Cs-134	0.3824E+04	0.8508E-21	0.1101E-14	0.4073E-04
Cs-136	0.2023E+02	0.4569E-23	0.3349E-15	0.1239E-04
Cs-137	0.3110E+05	0.7076E-20	0.6155E-15	0.2277E-04
Ba-139	0.3385E+00	0.7813E-25	0.1278E-14	0.4728E-04
Ba-140	0.7430E+02	0.1727E-22	0.1265E-14	0.4679E-04
La-140	0.1000E+00	0.2325E-25	0.1292E-16	0.4781E-06
La-141	0.8951E-02	0.2096E-26	0.1185E-16	0.4385E-06
La-142	0.3385E-02	0.7982E-27	0.1143E-16	0.4228E-06

Organic I (atoms)   0.0000E+00
Aerosols (kg)   0.0000E+00

Exhaust from CR to Environment Transport Group Inventory:

	Pathway Filter
Time (h) = 720.0000	
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

##
########

Cumulative Dose Summary

##
########

Time	Exclusion Area Bndry. Thyroid	Exclusion Area Bndry. TEDE	Low Population Zone Thyroid	Low Population Zone TEDE	Control Room Thyroid	Control Room TEDE
(hr)	(rem)	(rem)	(rem)	(rem)	(rem)	(rem)
TEDE (rem)						
0.03 0.1403E-05	0.4064E-01	0.1758E-02	0.5487E-02	0.2373E-03	0.3609E-04
0.17 0.1623E-03	0.1120E+01	0.4931E-01	0.1512E+00	0.6657E-02	0.4047E-02
0.28 0.6257E-03	0.2653E+01	0.1186E+00	0.3582E+00	0.1601E-01	0.1517E-01
0.50 0.2309E-02	0.6125E+01	0.2740E+00	0.8268E+00	0.3699E-01	0.5383E-01
1.18 0.2074E-01	0.3266E+02	0.1780E+01	0.4409E+01	0.2403E+00	0.3367E+00
1.80 0.6661E-01	0.6228E+02	0.3907E+01	0.8408E+01	0.5275E+00	0.7241E+00
2.00 0.8826E-01	0.6858E+02	0.4539E+01	0.9258E+01	0.6128E+00	0.8449E+00
3.00 0.2004E+00	0.6858E+02	0.4539E+01	0.1056E+02	0.9600E+00	0.1077E+01
8.00 0.1258E+01	0.6858E+02	0.4539E+01	0.1482E+02	0.3902E+01	0.1804E+01
24.00 0.7131E+01	0.6858E+02	0.4539E+01	0.2051E+02	0.1651E+02	0.4266E+01
96.00 0.1477E+02	0.6858E+02	0.4539E+01	0.3074E+02	0.3837E+02	0.6944E+01
720.00 0.3619E+02	0.6858E+02	0.4539E+01	0.6043E+02	0.1058E+03	0.1429E+02

##
########

I-131 Summary

##
########

Sprayed Region   Unsprayed Region

Annulus

Ce-141	0.4308E+01	0.1009E-23	0.2874E-16
0.1063E-05	0.1772E+00	0.4208E-25	0.2794E-16
Ce-143			
0.1034E-05	0.2270E+02	0.5429E-23	0.1732E-16
Ce-144			
0.6407E-06	0.6863E+00	0.1630E-24	0.1097E-16
Pr-143			
0.4060E-06	0.2485E+00	0.6067E-25	0.4908E-17
Nd-147			
0.1816E-06	0.3570E+01	0.1417E-23	0.3287E-15
Np-239			
0.1216E-04	0.2754E+01	0.1088E-23	0.1863E-19
Pu-238			
0.6894E-09	0.1703E+03	0.6761E-22	0.4202E-20
Pu-239			
0.1555E-09	0.5836E+02	0.2326E-22	0.5299E-20
Pu-240			
0.1961E-09	0.2165E+02	0.8663E-23	0.8924E-18
Pu-241			
0.3302E-07	0.1717E+00	0.6870E-25	0.2358E-21
Am-241			
0.8724E-11	0.6776E-01	0.2723E-25	0.9024E-19
Cm-242			
0.3339E-08	0.1611E+00	0.6527E-25	0.5280E-20
Cm-244			
0.1954E-09			

Control Room Transport Group Inventory:

	Atmosphere	Sump	Overlying Pool
Time (h) = 720.0000			
Noble gases (atoms)	0.4782E+18	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.5310E-18	0.0000E+00	0.0000E+00
Organic I (atoms)	0.1387E+13	0.0000E+00	0.0000E+00
Aerosols (kg)	0.3141E-18	0.0000E+00	0.0000E+00

	Deposition Surfaces	Recirculating Filter
Time (h) = 720.0000		
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.1462E+15
Organic I (atoms)	0.0000E+00	0.3992E+16
Aerosols (kg)	0.0000E+00	0.8697E-07

Filter 3--Environment to CR Transport Group Inventory:

	Pathway Filter
Time (h) = 720.0000	
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.4348E+22
Organic I (atoms)	0.1372E+25
Aerosols (kg)	0.7988E+01

Unfiltered--Environment to CR Transport Group Inventory:

	Pathway Filter
Time (h) = 720.0000	
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00

I-131

Time (hr)	(Curies)	I-131 (Curies)	I-131 (Curies)
0.03	0.6832E+00	0.2513E+06	0.1560E+04
0.17	0.1652E+02	0.9177E+06	0.3603E+05
0.28	0.3544E+02	0.1074E+07	0.1421E+06
0.50	0.9123E+02	0.1249E+07	0.2381E+06
1.18	0.4944E+03	0.3194E+07	0.6762E+06
1.80	0.9105E+03	0.3248E+07	0.6933E+06
2.00	0.9845E+03	0.9303E+06	0.5760E+06
3.00	0.9857E+03	0.9191E+05	0.9890E+05
8.00	0.7281E+03	0.1290E+06	0.2730E+05
24.00	0.3584E+03	0.1020E+06	0.2170E+05
96.00	0.7104E+02	0.5746E+05	0.1250E+05
720.00	0.5428E+02	0.4618E+05	0.1013E+05

Time (hr)	Environment I-131 (Curies)	Control Room I-131 (Curies)
0.03	0.7591E-01	0.2569E-05
0.17	0.3496E+00	0.6307E-04
0.28	0.7994E+00	0.1374E-03
0.50	0.1572E+01	0.2072E-03
1.18	0.2093E+01	0.5508E-03
1.80	0.4373E+01	0.6349E-03
2.00	0.2042E+01	0.5077E-03
3.00	0.5646E+00	0.1388E-03
8.00	0.3073E+01	0.1555E-03
24.00	0.1356E+02	0.1618E-03
96.00	0.2558E+02	0.5299E-04
720.00	0.2349E+02	0.2825E-04

1.6 Example Cases

1.6.1 Example Problem 1 Description

Example problem 1 is a containment leak from a pressurized water reactor (see Figure 1.6.1-1). It uses the TID-14844 release for the source term. As the iodine is released from the containment, the code calculates the dose at the low population zone. The sample is similar to acceptance test case 2, which has an analytic solution. The data used will vary according to plant and will be known by the user. In this sample problem, the user will be guided through each screen to familiarize him or her with the general process.
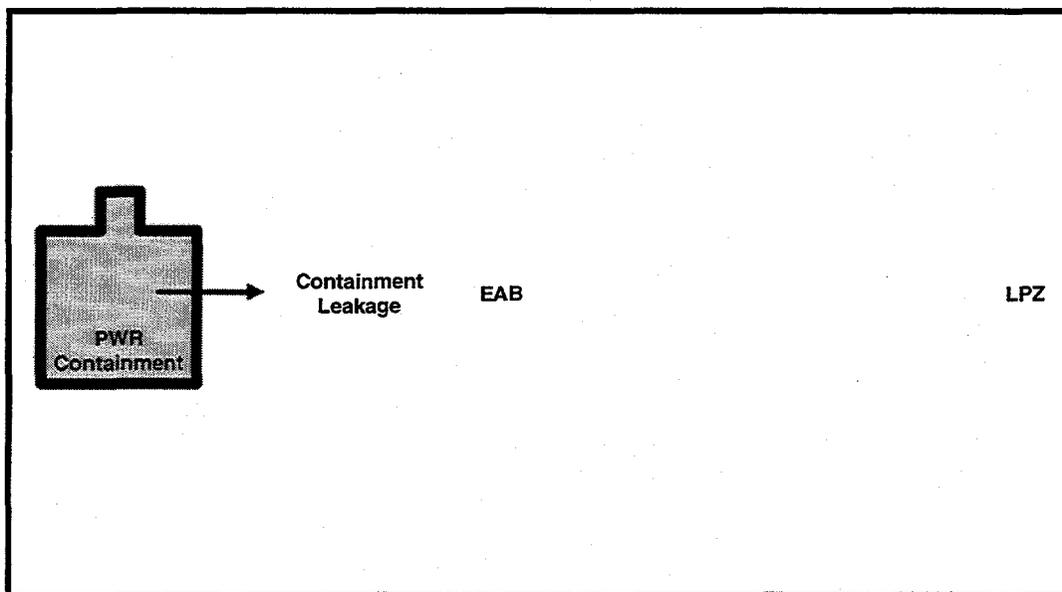
Figure 1.6.1-1. PWR Containment Leakage

Source Term

> Release fractions and timing: TID-14844, Table IV with modifications per NRC Regulatory Guides 1.3 and 1.4 (removes mixed fission products and details iodine fractions) and further modified as described below.

Start of release: 0.0000 hr

Iodine fractions: Fraction of released iodine chemical form:

> Elemental: 0.9100
> Organic: 0.0400
> Aerosol: 0.0500

Inventory: TID-14844 example normalized core inventory.

Reactor power: 1932 MWt

Plant Model

Containment volume: $0.1730E+07$ ft^3

Environment

Containment leakage: Air leakage   from: Containment   to: Environment

Scenario Description

Containment leak rate: 0.1200 %/day

Dose Parameters

LPZ X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.1350E-03
	8.0000	0.1000E-03
	24.0000	0.5400E-04
	96.0000	0.2200E-04

Environmental

Breathing Rates:	Time (hr)	Breathing Rate (m^3/s)
	0.0000	0.3470E-03
	8.0000	0.1750E-03
	24.0000	0.2320E-03

1.6.1.1 RADTRAD Screen Input

As noted earlier, the input should be entered in a sequential order, as opposed to partially entering the data on a screen, moving on to another screen, and then returning. While the code has been heavily tested, all possible patterns of inputting data have not.

To run this example problem, the following steps should be followed:

Go to the RADTRAD directory and type **RADTRAD**; this will bring up a welcome screen.

Touch any alphanumeric key; this will bring up screen number 0000, which allows the user to input, execute, or examine a case.

Enter the number 1, or click on the pad labeled *Plant Model*. This will bring up screen number 1000, the **Plant Model** menu.

Since this is a new case, there is no reason to touch the first pad and retrieve an old plant model. *Enter the number 2*, or click on the pad labeled *Nuclide Inventory*. This will bring up screen number 1200.

The nuclide inventory menu allows the user to initialize the core radionuclide inventory. There are several defaults shown that are detailed in Section 1.4.3.2. The user should *select the button under Default TID Inventory*. The plant power is used as a multiplier on the inventory; hence a

3000-MWt plant will have three times the inventory of radionuclides as a 1000 MWt. For this case, the user should *input 1.932E+03 on the pad next to the label Plant Power*. When the user selected the TID button for the default inventory the location of the file came up on the *File Name* pad. If the user wants to follow only the ^{131}I nuclide, there is a TID inventory file available called "DEFAULTS\TID_I131.NIF". The user should leave the file name alone for this example and *click on* **OK**. This will return the user to screen 1000.

The user should continue developing the plant model by *entering the number 3*, or clicking on the pad labeled *Compartment Description*. This will bring up screen 1300.

Screen 1300 is the **Select Compartment** screen and at this point should show *Unused* for all 10 compartments. The first unused is highlighted; the user should *click on* **EDIT** or hit RETURN. This will bring up screen 1310.

Screen 1310 allows the user to identify the compartments. The user *should enter Containment on the pad following the label Compartment Name*. A containment is neither a control room nor an environment, so the user should *select the button next to Other on the pad next to the label Compartment Type*. The user should *input 0.1730E+07 on the pad next to the label Compartment Volume*. In this example problem, no engineered or natural safety features will be activated, hence the *user should click on* **OK**. This will return the user to screen number 1300.

Screen number 1300 now has the label *Containment* in the first row and the second row should be highlighted. The user should again *click on* **EDIT** to add the next compartment for this problem. This will return the user to screen 1310.

On screen 1310, *the user should enter Environment on the pad following the label Compartment Name. The user should select the button next to Environment on the pad next to Compartment Type*. Note that both the volume and features options have disappeared. This is because the environment does not have either a set volume or engineered safety features. The user should click on **OK**. This will return the user to screen number 1300.

Screen 1300 now has the two labeled volumes, *Containment* and *Environment*, that this example requires. The user should *click on* **OK**. This will return the user to screen number 1000.

The user should continue developing the plant model by *entering the number 4*, or clicking on the pad labeled *Transfer Pathways*. This will bring up screen 1400.

Screen 1400 is the **Select Pathway** screen, which allows the user to define how radionuclides will move between the compartments just defined. The user *should highlight the first "Unused" pathway and click on* **EDIT**. This will bring up screen 1410.

Screen 1410 is the **Transfer Pathway Description** screen. The user *should enter Air Leakage on the pad beneath the label Pathway Name*. In this example both air and radionuclides will leak from the containment to the environment. The user should now *double click on the pad beneath the label Pathway from Compartment*. This will bring up screen number 1411.

Screen 1411 has the list of the compartments the user defined previously. The user *should select the first compartment, Containment, and then click an* **OK** to return to screen 1410. The input system now knows where the flow is coming from.

Screen 1410 now has the name *Containment* on the pad below the *Pathway from Compartment*. The *user should double click on the pad beneath the label Pathway to Compartment* to identify the environment as the receiving volume of the flow. This will bring up screen 1411, where the user *should highlight the environment compartment and click* **OK** to return to screen 1410. The user should *select the button next to the Air Leakage* label on the list of *Transfer Mechanisms*. This will activate the correct linkages for later input. The user should *click on* **OK**. This will return the user to screen number 1400.

Screen 1400 now shows the only transport path, *Air Leakage*. The user should *click on* **OK**. This will return the user to screen number 1000.

The user *may enter the number 5, or click on the pad labeled Review Plant Model*, to look at the input selected for the plant model. Screen number 1500 cannot be edited; therefore any changes to the input can only be made by returning to screen 1000 and selecting the appropriate sub-screen to change the data. The return to screen 1000 from this screen is accomplished by hitting the ESC key on the keyboard.

The user should *enter the number 6, or click on the pad labeled Save Plant Model*, to save input data. This will activate screen number 1600. It is recommended that the *user select an appropriate name with the convention of XXX.PMF* where the PMF stands for plant model file. For this example use *SAMPLE1.PMF*. *Clicking on* **OK** will bring up screen number 1000.

The plant model is now complete. *Enter the number 7, or click on the pad labeled Return to Main Menu* to return to screen number 0000 and continue the input process.

The user should *enter the number 2, or click on the pad labeled Scenario Description* to continue the development of the input example. This will bring up screen number 2000.

Screen 2000 is the controlling screen for describing the scenario. As with the plant model description, there is no model to retrieve, so the user should *enter the number 2, or click on the pad labeled Source Term Parameters*. This will bring up screen 2200.

Screen 2200 lets the user describe the radionuclide release. The user should *enter the number 1, or click on the pad labeled Source Term Compartment*; this will bring up screen 2210. Screen 2210 allows the user to choose where the source is located. In this case, the user should *highlight the Containment compartment and click on* **OK** to return to screen 2200. The user *should enter the number 2, or click on the pad labeled Release Fractions and Timing*. This will bring up screen 2220.

Screen 2220 allows the user to choose from several default release systems, or to design his or her own. *The TID Release Type should be selected.* Note that it has been preselected because this example chose the TID inventory for the plant model. There is no delay time between reactor shutdown and radionuclide release in this example, so the default value of 0.0 hr is

correct. Note that the TID release fraction file table has been listed on the file name pad. The user may change it by clicking on **EDIT** to the right. For this example, the user should *click on* **OK** to return to screen 2200.

This case will not activate the decay chain processing, nor the daughtering system, so the user will skip pad 3 and *enter the number 4, or click on the pad labeled Iodine Chemical Form.* This will activate screen number 2240. The user should *enter 0.91, 0.04, and 0.05 for elemental, organic, and aerosol iodine chemical fractions* for this example. These values are typical of the TID source term assumptions. The user *should click on* **OK** to return to screen 2200. The source term form has now been described. The user *should enter the number 5, or click on the pad labeled Return to Scenario Description* to return to screen number 2000.

The user should continue developing the scenario model by *entering the number 3, or clicking on the pad labeled Compartment Features.* This will bring up screen 2300. Screen 2300 lists the two compartments described in the plant model. The user should *highlight the Containment compartment and click on* **EDIT**. This will bring up screen number 2300A.

Screen 2300A allows the user access to the removal features selected in the plant model. If a feature was selected, an X will be in the box to the left of the appropriate pad, indicating that it had been selected and that the pad could be activated. Detailed output is not needed for this case so the default is correct. The user should *select* **OK**, which will return to screen number 2300. There is also nothing to add to the environment volume, so the user should *select* **OK** again and return to screen number 2000.

The user should continue developing the scenario model by *entering the number 4, or clicking on the pad labeled Transfer Pathways.* This will bring up screen 2400. Screen 2400 lists the air leakage pathway described by the plant model. Highlighting this pathway and clicking on **EDIT** will bring up the screen associated with this transfer pathway, in this case screen number 2440T.

Screen 2440T allows the user to enter the leakage flow versus time. In this example *the user should select the top row of Time and then enter 0.0, 0.12, 720.0, and 0.12*, with a return after each number. This should fill the table with two time entries (0.0 and 720 hr) and two leakage entries (both 0.12%/day). The user *should select the Yes button* on the pad next to the label *Select User Leakage Rates. Yes* allows the table to be saved and be used by the code, a *No* only allows it to be saved. The user should *click on* **OK** to return to screen 2400. Because this example uses only one transport path, the user should *click on* **OK** again to return to screen number 2000.

The user should continue developing the scenario model by *entering the number 5, or clicking on the pad labeled Dose Parameters.* This will bring up screen 2500. Screen 2500 controls the dose calculation. The user should *enter the number 1, or click on the pad labeled Select Dose Conversion Factors.* This will bring up screen 2510.

Screen 2510 allows the user to select the dose conversion factors to be used in the calculation. Several default tables are given and the user should verify that the button associated with the

FGR 11 and 12 label has been selected. The default tables are listed in Section 1.4.3.3. The user should *click on the pad labeled TID-14844* and the **OK** button to return to screen 2500.

The user should *enter the number 2, or click on the pad labeled Create/Modify Dose Locations* to continue the input of dose information. This action will bring up screen 2520, which will eventually list all the locations where the user will want a dose to be calculated. Typically, the user seeks to calculate doses in the control room, the exclusion area boundary, and at the low population zone. In this example calculation, only the low population zone information will be input. *Clicking on* **EDIT** will bring up screen 2520A and allow the user to input this data.

On screen 2520A the user should *enter Low Population Zone on the pad beneath the label Location Name.* The user should then *double click on the pad beneath the label Compartment Name.* This action will bring up screen 2521 and a list of all compartments. The user *should highlight the Environment compartment and click on* **OK.** This will return the user to screen 2520A. The user *should verify that the button labeled Environment under Selected Type has been selected.* The user should *double click on Edit Dose Location Parameters* to finish the dose input. This action will bring up screen 2523.

Screen 2523 allows the user to input dilution and breathing rates. If the *user selects the top row of the left Time table and inputs, 0.0   0.1350E-03 0.0 0.3470e-03 8.0 0.1000e-03 8.0 0.1750e-03 24.0 0.5400e-04 24.0 0.2320e-03 96.0 0.2200e-04* with a return after each value, the result should be two tables. The concentration table should have four time and value entries and the breathing rate table should have three entries. The *user selects* **OK** to return to screen 2520A. The user selects **OK** again to return to screen 2500.

The user *enters 3, or clicks on the pad labeled Return to Scenario Description Menu* to move from screen 2500 to screen 2000. The *user may enter the number 6, or click on the pad labeled Review Scenario Description* to look at the input selected for the scenario description. Screen number 2600 cannot be edited; therefore any changes to the input can only be made by returning to screen 2000 and selecting the appropriate subscreen to change the data. The return to screen 2000 from this screen is obtained by using the ESC key on the keyboard.

The user should *enter the number 7, or click on the pad labeled Save Scenario Description* to save input data. This will activate screen number 2700. It is recommended that the *user select an appropriate name with the convention of XXX.SDF* where the SDF stands for scenario description file. It is recommended that the **XXX** used for the scenario description file be the same as the **XXX** for the plant model file. For this example use SAMPLE1.SDF. Clicking on **OK** will bring up screen number 2000.

The user *enters the number 8, or clicks on the pad labeled Return to Main Menu* to return to screen number 0000. The input has now been entered and the user should *enter the number 3, or click on the pad labeled Calculate Results* to move to screen 3000 and start execution.

Screen 3000 allows the user to control several items including:

1. The name of the output file. The default is OUTPUT.TXT

2. The supplemental time steps. The user adds additional time steps to the calculation using the maximum time step allowed table. For most cases, a time step of 0.25 hr (15 min) for the first 4 hr, a 1-hr time step between 4 and 24 hr, and a 4-hr time step between 1 day and 30 days are reasonable.

3. Amount of output printed. This depends on whether the user wants information only when a phenomenon changes (for example, the breathing rate changes at 8 and 24 hr) or wants the output for all time steps (this includes those from the supplemental time steps).

4. Type of output printed. The run-time removal coefficients are included when the *Include Model Run-Time Information* button is selected. In addition, the output of the information input is controlled from the plant model and the scenario description.

5. Execution initialization. The user should *click on the* **CALCULATE** *button* to begin execution. The pad to the left of the button should change from empty to full at a speed related to the execution speed (in this case very quickly; ~ a few seconds). The output file will be displayed on screen when the calculation terminates.

The general output is described in Section 1.6.2. In this case, the user should compare the resulting output with the output in the following section. The user may exit RADTRAD by pulling down the file menu and clicking on **EXIT**. This action will bring up screen number 5000, which can be used to save the input files. When the *user clicks on* **OK**, RADTRAD will return to the DOS command line.

1.6.1.2 Example Problem 1 Output

```
############################################
##########          RADTRAD Version 2.12   06/19/97
##########

12:00:52.94

############################################
##########
############################################
##########                File information
##########
############################################
##########

Plant filename              = D:\RADMANUA\SAMPLE1.PMF
Inventory filename          = DEFAULTS\TID_DEF.NIF
Scenario filename           = D:\RADMANUA\SAMPLE1.SDF
Release filename            = DEFAULTS\TID_DEF.RFT
Dose conversion filename    = DEFAULTS\TID14.INP

############################################
##########
############################################
##########              Plant Description
##########
############################################
##########

Number of Nuclides = 14

Inventory Power  =  0.1000E+01 MWth
Plant Power Level =  0.1932E+04 MWth

Number of compartments      =     2

Compartment information

Compartment number   1  (Source term compartment)
Name: Containment
Compartment volume =  0.1730E+07 (Cubic feet)
```

Pathways into and out of compartment   1
    Pathway to compartment number   2: Air Leakage

Compartment number   2
Name: Environment
Pathways into and out of compartment   2
    Pathway from compartment number 1: Air Leakage

Total number of pathways =   1

```
############################################
##########                Scenario Description
##########
############################################
##########
```

Iodine fractions
    Aerosol   =   0.5000E-01
    Elemental =   0.9100E+00
    Organic   =   0.4000E-01

COMPARTMENT DATA

Compartment number   1: Containment

Compartment number   2: Environment

PATHWAY DATA

Pathway number   1: Air Leakage

Convection Data
    Time (hr)   Flow Rate (% / day)
    0.0000E+00   0.1200E+00
    0.7200E+03   0.1200E+00

LOCATION DATA
    Location Low Population Zone   is in
compartment   2

Location X/Q Data
    Time (hr)   X/Q (s * m^-3)
    0.0000E+00   0.1350E-03

```
0.8000E+01    0.1000E-03
0.2400E+02    0.5400E-04
0.9600E+02    0.2200E-04

          Location Breathing Rate Data
      Time (hr)       Breathing Rate (m^3 *
sec^-1)
      0.0000E+00           0.3470E-03
      0.8000E+01           0.1750E-03
      0.2400E+02           0.2320E-03

##################################################
##################
                  Dose Output
##################################################
##################

Low Population Zone Doses:

Time (h) =    0.0100      Whole Body    Thyroid
TEDE                                               TEDE
Delta dose (rem)          0.2676E-02    0.2205E+00    0.9725E-02
Accumulated dose (rem)    0.2676E-02    0.2205E+00    0.9725E-02

Low Population Zone Doses:

Time (h) =    8.0000      Whole Body    Thyroid
TEDE                                               TEDE
Delta dose (rem)          0.4275E+01    0.3523E+03    0.1554E+02
Accumulated dose (rem)    0.4278E+01    0.3525E+03    0.1555E+02

Low Population Zone Doses:

Time (h) =    24.0000     Whole Body    Thyroid
TEDE                                               TEDE
Delta dose (rem)          0.6338E+01    0.2634E+03    0.1476E+02
Accumulated dose (rem)    0.1062E+02    0.6159E+03    0.3030E+02

Low Population Zone Doses:

Time (h) =    96.0000     Whole Body    Thyroid
TEDE                                               TEDE
Delta dose (rem)          0.1537E+02    0.8466E+03    0.4243E+02
Accumulated dose (rem)    0.2598E+02    0.1463E+04    0.7274E+02

Low Population Zone Doses:

Time (h) =    720.0000    Whole Body    Thyroid
TEDE                                               TEDE
Delta dose (rem)          0.5332E+02    0.2938E+04    0.1472E+03
Accumulated dose (rem)    0.7931E+02    0.4400E+04    0.2200E+03

##################################################
###################  Cumulative Dose Summary  ####
##################################################
##################

                      Low Population Zone
  Time        Thyroid                 TEDE
  (hr)        (rem)                   (rem)
  0.01        0.2205E+00              0.9725E-02
  8.00        0.3525E+03              0.1555E+02
  24.00       0.6159E+03              0.3030E+02
  96.00       0.1463E+04              0.7274E+02
  720.00      0.4400E+04              0.2200E+03

##################################################
#######################  I-131 Summary  ##########
##################################################
##################

                               Containment
Environment
  Time (hr)   I-131 (Curies)          I-131 (Curies)
  0.01        0.1185E+08              0.2962E+01
  8.00        0.1184E+08              0.4732E+04
  24.00       0.1183E+08              0.9471E+04
  96.00       0.1179E+08              0.4253E+05
  720.00      0.1143E+08              0.3622E+06
```

1.6.2 Example Problem 2 Description

The second example problem is a boiling water reactor with a specified TID ^{131}I leak through the main steam line to the condenser and then to the environment (see Figure 1.6.2-1). In this example there will be a specified deposition and reevolution of the iodine on the pipe walls. After the release from the turbine building, the code will calculate the doses at the exclusion area boundary, the low population zone, and in the control room. This case was also used for acceptance test case 13.

The data below should be known by the user. In general the user should define the plant model first, that is, those values going into screen numbers between 1000 and 1600, and then define the scenario. After developing the model, the user can compare the input with that provided in Section 1.6.2.1.
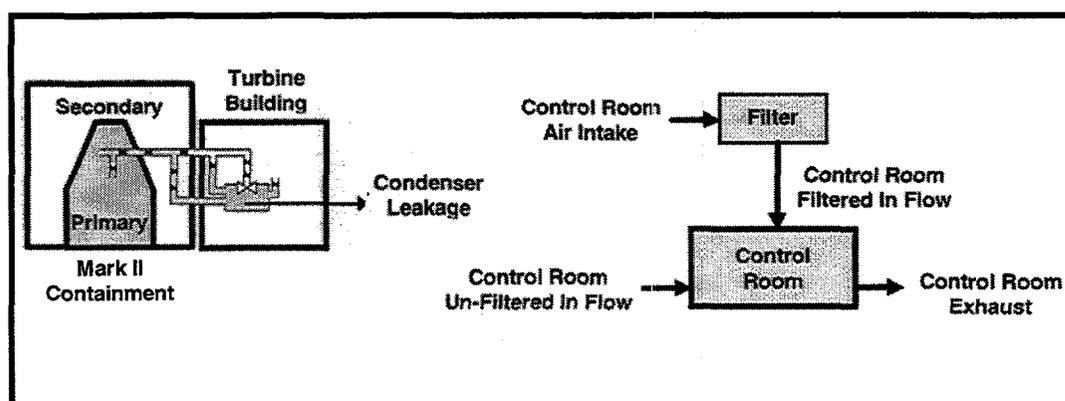
Figure 1.6.2-1. BWR-Mark II Containment Control Room Detail

Source Term

Release fractions and timing:	TID-14844, Table IV with modifications per NRC Regulatory Guide 1.3 and further modified as described below.
	[screen number 2220]
Start of release: 0.0000 hr	
	[screen number 2220]
Iodine fractions:	

Fraction of released iodine chemical form:

Elemental: 0.8760
Organic: 0.0740
Aerosol: 0.0500

[Note that these values are not the standard 0.91, 0.04 and 0.05. In this case there is a specified iodine deposition. The iodine deposition was obtained from the Cline model, which accounts for deposition and reevolution due to chemisorption. This results in the growth of organic iodines over time at the expense of elemental iodines. To implement these effects in RADTRAD, it was necessary to generate the maximum organic iodine inventory from the fraction released plus the fraction produced and then to deposit decreasing amounts of the organics over time. Therefore the environmental release is initially a small amount of organic iodines followed by a larger amount of organics, thus duplicating the Cline results.]

[screen number 2240]

Inventory: TID-14844 example normalized core inventory modified as follows:

^{131}I only [Note that this is not one of the default options. The group of inventory files supplied with RADTRAD is available in the Defaults subdirectory.] The user should use file TID_I131.NIF for this case

[screen number 1200]

Reactor power: 3441 MWt

[screen number 1200]

Plant Model

Containment volume: $0.3892E+06 \text{ ft}^3$

Effective condenser volume: $0.9860E+05 \text{ ft}^3$

Control room volume: $0.1100E+06 \text{ ft}^3$

Environment

[all four values for name and the three values for volume are on screen number 1310]

Containment leakage:	Air leakage	from: Containment	to: Condenser
Condenser leakage:	Piping	from: Condenser	to: Environment
Filter:	Filtered pathway	from: Environment	to: Control room
CR unfiltered inflow:	Filtered Pathway	from: Environment	to: Control room

| CR exhaust: | Filtered Pathway | from: Control room | to: Environment |

[All five transfer pathways are defined (name, from and to compartments, and transfer mechanism) on screen number 1410.]

Scenario Description

Containment leak rate: 1.851%/day

[screen number 2440T]

Condenser leak rate: 0.7666 cfm

[screen number 2410T]

Condenser

Pipe deposition:	Time (hr)	Decontamination Factors			Efficiency (%)
		Aerosol	Elemental	Organic	
	0-48	900.	900.	5.555	82
	48-96	900.	900.	2.707	63
	96-200	900.	900.	1.639	39
	200-300	900.	900.	1.219	18
	300-	900.	900.	1.0417	4

[A decontamination factor of 900 is the equivalent of a 100% efficient deposition, as assumed in the Cline model. The effect of reducing deposition efficiency for the organics reflects reevolution due to chemisorption effects, which releases organic iodine from the interaction of elemental iodine and the material on the wall surface. These values, when used with larger organic release fractions, replicate the results of the Cline model for release to the environment through a pipe and condenser. Screen number 2410T]

CR filter flow rate: 5800 cfm

[screen number 2420T]

CR filter efficiencies:
Elemental iodine   99.0000%
Organic iodine   0.0000%
Aerosols   99.0000%

[screen number 2420T]

CR unfiltered inflow: 10 cfm

[This accounts for leakage into the room through doorways and other unfiltered leaks. All the efficiencies will be 0.0% for this example. Screen number 2420T]

CR exhaust: 5810 cfm

[This exhaust is through filters and will not affect the environmental dose. All the efficiencies are set at 100% for this example. Screen number 2420T]

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1100E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.5200E-04
8.0000	0.3600E-04
24.0000	0.1600E-04
96.0000	0.5300E-05

Environmental
breathing rates:

Time (hr)	Breathing Rate (m^3/s)
0.0000	0.3470E-03
8.0000	0.1750E-03
24.0000	0.2320E-03

[The locations are on screen number 2520 and the values are on screen number 2523.]

CR filter X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.3320E-03
8.0000	0.1960E-03
24.0000	0.7640E-04
96.0000	0.2190E-04

[These values are also used for the unfiltered inlets and are input on screen number 2420T2 with the efficiencies and flows.]

CR breathing rates: Time (hr)   Breathing Rate (m^3/s)

0.0000   0.3470E-03

CR occupancy factor: Time (hr)   Occupancy Factor

0.0000   1.000

24.000   0.600

96.0000   0.400

[The locations are on screen number 2520 and the values are on screen number 2522.]

1.6.2.2 Example Problem 2 Output

```
###########################################################
            RADTRAD Version 2.12  06/12/97  20:43:24.74
###########################################################

###########################################################
#                     File information
###########################################################
#
Plant filename             = accept\test13.pmf
Inventory filename         = DEFAULTS\TID_I131.NIF
Scenario filename          = accept\test13.sdf
Release filename           = DEFAULTS\TID_DEF.RFT
Dose conversion filename   = DEFAULTS\TID14.INP
###########################################################
#                     Plant Description
###########################################################
#

Number of Nuclides = 14

Inventory Power    = 0.1000E+01 MWth
Plant Power Level  = 0.3441E+04 MWth

Number of compartments       =     4

Compartment information

Compartment number  1  (Source term compartment)
Name: Containment
Compartment volume =   0.3892E+06 (Cubic feet)
Pathways into and out of compartment  1
    Pathway to compartment number   2: MSIV Leak to
Condenser

Compartment number  2
Name: Condenser
Compartment volume =   0.9860E+05 (Cubic feet)
Pathways into and out of compartment  2
    Pathway to compartment number   3: Leakage to
Environment
    Pathway from compartment number  1: MSIV Leak to
Condenser

Compartment number  3
Name: Environment
Pathways into and out of compartment  3
    Pathway to compartment number   4: Filtered Input to
Control Room
    Pathway to compartment number   4: Unfiltered Input to
Control Room
    Pathway from compartment number  2: Leakage to
Environment
    Pathway from compartment number  4: Control Room
Exhaust

Compartment number  4
Name: Control Room
Compartment volume =   0.1100E+06 (Cubic feet)
Pathways into and out of compartment  4
    Pathway to compartment number   3: Control Room
Exhaust
    Pathway from compartment number  3: Filtered Input to
Control Room
    Pathway from compartment number  3: Unfiltered Input to
Control Room

Total number of pathways =    5

###########################################################
#
#                  Scenario Description
###########################################################
#

Iodine fractions
    Aerosol    =    0.5000E-01
    Elemental  =    0.8760E+00
    Organic    =    0.7400E-01

COMPARTMENT DATA

Compartment number    1: Containment

Compartment number    2: Condenser

Compartment number    3: Environment

Compartment number    4: Control Room

PATHWAY DATA

Pathway number  1: MSIV Leak to Condenser

    Convection Data
    Time (hr)            Flow Rate (% / day)
    0.0000E+00             0.1850E+01
```

```
        0.7200E+03        0.1850E+01

Pathway number  2: Leakage to Environment

   Piping:  Removal Data

      Time (hr)   Flow Rate (cfm)                  DF (s^-1)
                               Aerosol            Elemental
Organic
   0.0000E+00                  0.7666E+00          0.2500E+00
 0.4628E-03
   0.4000E+02                  0.7666E+00          0.2500E+00
 0.3967E-03
   0.1000E+03                  0.7666E+00          0.2500E+00
 0.3267E-03
   0.2000E+03                  0.7666E+00          0.2500E+00
 0.2925E-03
   0.4000E+03                  0.7666E+00          0.2500E+00
 0.2778E-03

Pathway number  3: Filtered Input to Control Room

   Pathway Filter: Removal Data

   Filter flow rate =  0.5800E+04 (cfm)

      Time (hr)              Filter efficiency (%)
                 Aerosol              Elemental
Organic
   0.0000E+00     0.9900E+02           0.9900E+02
 0.0000E+00
   0.7200E+03     0.9900E+02           0.9900E+02
 0.0000E+00

Pathway number  4: Unfiltered Input to Control Room

   Pathway Filter: Removal Data

   Filter flow rate =  0.1000E+02 (cfm)

      Time (hr)              Filter efficiency (%)
                 Aerosol              Elemental
Organic
   0.0000E+00     0.0000E+00           0.0000E+00
 0.0000E+00
   0.7200E+03     0.0000E+00           0.0000E+00
 0.0000E+00

Pathway number  5: Control Room Exhaust

   Pathway Filter: Removal Data


   Filter flow rate =  0.5810E+04 (cfm)

      Time (hr)              Filter efficiency (%)
                 Aerosol              Elemental
Organic
   0.0000E+00     0.0000E+00           0.0000E+00
   0.7200E+03     0.0000E+00           0.0000E+00
 0.0000E+00

LOCATION DATA
 3   Location Exclusion Area Bndry    is in compartment

Location X/Q Data
   Time (hr)      X/Q (s * m^-3)
   0.0000E+00     0.1100E-02
   0.2000E+01     0.0000E+00

Location Breathing Rate Data
   Time (hr)      Breathing Rate (m^3 * sec^-1)
   0.0000E+00     0.3470E-03
   0.8000E+01     0.1750E-03
   0.2400E+02     0.2320E-03
 3   Location Low Population Zone     is in compartment

Location X/Q Data
   Time (hr)      X/Q (s * m^-3)
   0.0000E+00     0.5200E-04
   0.8000E+01     0.3600E-04
   0.2400E+02     0.1600E-04
   0.9600E+02     0.5300E-05

Location Breathing Rate Data
   Time (hr)      Breathing Rate (m^3 * sec^-1)
   0.0000E+00     0.3470E-03
   0.8000E+01     0.1750E-03
   0.2400E+02     0.2320E-03
   Location Control Room            is in compartment  4

Location Breathing Rate Data
   Time (hr)      Breathing Rate (m^3 * sec^-1)
   0.0000E+00     0.3470E-03
   0.7200E+03     0.0000E+00

Location Occupancy Factor Data
   Time (hr)      Occupancy Factor
   0.0000E+00     0.1000E+01
   0.2400E+02     0.6000E+00
   0.9600E+02     0.4000E+00
   0.7200E+03     0.0000E+00
```

USER SPECIFIED TIME STEP DATA - SUPPLEMENTAL TIME STEPS

Time	Time step
0.0000E+00	0.2500E+00
0.8000E+01	0.1000E+01
0.2400E+02	0.4000E+01
0.7200E+03	0.0000E+00

```
##################################################
###########
Output    Dose, Detailed model and Detailed Inventory
##################################################
###########
```

Exclusion Area Bndry Doses:

Time (h) = 0.0100	Whole Body	Thyroid	TEDE
Delta dose (rem)	0.9846E-08	0.5481E-04	0.1679E-05
Accumulated dose (rem)	0.9846E-08	0.5481E-04	0.1679E-05

Low Population Zone Doses:

Time (h) = 0.0100	Whole Body	Thyroid	TEDE
Delta dose (rem)	0.4654E-09	0.2591E-05	0.7935E-07
Accumulated dose (rem)	0.4654E-09	0.2591E-05	0.7935E-07

Control Room Doses:

Time (h) = 0.0100	Whole Body	Thyroid	TEDE
Delta dose (rem)	0.8487E-13	0.1096E-07	0.3337E-09
Accumulated dose (rem)	0.8487E-13	0.1096E-07	0.3337E-09

Control Room Atmosphere Nuclide Inventory:

Time (h) = 0.0100	Atoms	kg	Ci

```
Bq
I-131
0.1871E+03   0.1875E+09   0.4080E-16   0.5058E-08
```

Control Room Transport Group Inventory:

Time (h) = 0.0100	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Organic I (atoms)	0.1875E+09	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00	0.0000E+00

Time (h) = 0.0100	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00

Filtered Input to Control Room Transport Group Inventory:

Time (h) = 0.0100	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.3133E+13
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.6506E-16

Unfiltered Input to Control Room Transport Group Inventory:

Time (h) = 0.0100	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Control Room Exhaust Transport Group Inventory:

Time (h) = 0.0100	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

*** Intermediate time steps not edited ***

Exclusion Area Bndry Doses:

Time (h) = 720.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	0.0000E+00	0.0000E+00	0.0000E+00
Accumulated dose (rem)	0.5083E-04	0.2830E+00	0.8666E-02

Low Population Zone Doses:

Time (h) = 720.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	0.2558E-01	0.9523E+02	0.2925E+01
Accumulated dose (rem)	0.3957E-01	0.1472E+03	0.4521E+01

Control Room Doses:

Time (h) = 720.0000

	Whole Body	Thyroid	TEDE
Delta dose (rem)	0.1797E-02	0.2321E+03	0.7067E+01
Accumulated dose (rem)	0.2914E-02	0.3762E+03	0.1146E+02

Control Room Atmosphere Nuclide Inventory:

Time (h) = 720.0000

	Atoms	kg	Ci	Bq
I-131	0.1823E+15	0.3966E-10	0.4917E-02	0.1819E+09

Control Room Transport Group Inventory:

Time (h) = 720.0000

	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	0.0000E+00	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.2785E+11	0.0000E+00	0.0000E+00
Organic I (atoms)	0.1823E+15	0.0000E+00	0.0000E+00
Aerosols (kg)	0.3458E-15	0.0000E+00	0.0000E+00

Time (h) = 720.0000

	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00

Filtered Input to Control Room Transport Group Inventory:

Time (h) = 720.0000

	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.1033E+25
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.1283E-01

Unfiltered Input to Control Room Transport Group Inventory:

Time (h) = 720.0000

	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Control Room Exhaust Transport Group Inventory:

Time (h) = 720.0000

	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

###

Cumulative Dose Summary

###

Time (hr)	Control Room TEDE (rem)	Control Room Thyroid (rem)	Exclusion Area Bndry TEDE (rem)	Exclusion Area Bndry Thyroid (rem)	Low Population Zone TEDE (rem)	Low Population Zone Thyroid (rem)
0.01	0.5481E-04	0.1679E-05	0.2591E-05	0.7935E-07	0.1096E-07	0.3337E-09
2.00	0.2830E+00	0.8666E-02	0.1338E-01	0.4097E-03	0.6145E-01	0.1871E-02
8.00	0.2830E+00	0.8666E-02	0.2143E+00	0.6563E-02	0.3766E-01	0.1237E+01
24.00	0.2830E+00	0.8666E-02	0.8089E+00	0.2488E-01	0.2272E+00	0.7460E+01
40.00	0.2830E+00	0.8666E-02	0.1503E+01	0.4619E-01	0.3278E+00	0.1076E+02
96.00	0.2830E+00	0.8666E-02	0.7362E+01	0.2261E+00	0.1072E+01	0.3520E+02
100.00	0.2830E+00	0.8666E-02	0.7558E+01	0.2322E+00	0.1104E+01	0.3626E+02
200.00	0.2830E+00	0.8666E-02	0.1634E+02	0.5020E+00	0.1752E+01	0.5753E+02
400.00	0.2830E+00	0.8666E-02	0.5195E+02	0.1596E+01	0.4390E+01	0.1442E+03
720.00	0.2830E+00	0.8666E-02	0.1472E+03	0.4521E+01	0.1146E+02	0.3762E+03

###

I-131 Summary

###

Time (hr)	Containment I-131 (Curies)	Condenser I-131 (Curies)	Environment I-131 (Curies)
0.01	0.2110E+08	0.8133E+02	0.1329E-03

2.00		
0.1611E+00	0.2107E+08	0.3241E+05
8.00		
0.6757E+00	0.2097E+08	0.1294E+06
24.00		
0.7989E+01	0.2072E+08	0.3846E+06
40.00		
0.5120E+02	0.2046E+08	0.6347E+06
96.00		
0.1423E+03	0.1960E+08	0.1471E+07
100.00		
0.1480E+03	0.1954E+08 ·	0.1529E+07
200.00		
0.3401E+03	0.1809E+08	0.2875E+07
400.00		
0.6738E+03	0.1550E+08	0.5083E+07
720.00		
0.1051E+04	0.1211E+08	0.7517E+07

1.6.3 Example Problem 3 Description

The third example problem is an advanced PWR design with a specified NUREG-1465 source term released into a sprayed zone. Only part of the containment is sprayed and there is mixing between the two parts and natural deposition in the unsprayed part. There is an annulus surrounding the containment that has an exhaust filter (see Figure 1.6.3-1). There is a release to the environment from the annulus and both the sprayed and unsprayed portions of the containment. The code will calculate the doses at the exclusion area boundary, the low population zone, and in the control room. This case was also used for acceptance test case 23.

The data below should be known by the user. In general the user should define the plant model first, that is, those values going into screen numbers starting with 1, and then define the scenario. After developing the model, the user can compare the input with that provided in Section 1.6.3.1.
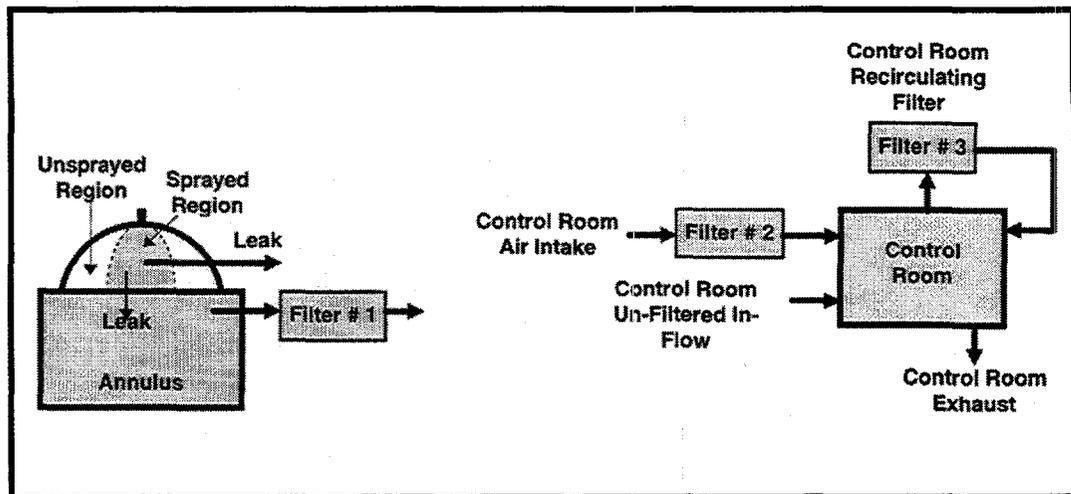
Figure 1.6.3-1. Advanced PWR Control Room Detail

Source Term

Release fractions and timing:	NUREG-1465, Tables 3.12 and 3.13.
	[screen number 2220]
Start of release: 0.0000 hr	
	[screen number 2220]

Iodine fractions: Fraction of released iodine chemical form:

Aerosol:	0.9500
Elemental:	0.0485
Organic:	0.0015

Inventory: Normalized MACCS Sample 3412 MWt PWR core inventory.

Reactor power: 3992 MWt

[screen number 1200]

Plant Model

Sprayed containment volume: $0.2740E+07$ ft^3

Unsprayed containment volume: $0.6011E+06$ ft^3

Annulus volume: $0.6162E+06$ ft^3

Control room volume: $0.6731E+05$ ft^3

             Filter #3:   Recirculation filter from: Control Room to: Control Room

Environment

[All five values for name, four values of the volume, the presence of sprays and natural deposition in the containment, and the recirculation filter feature for the control room use screen number 1310.]

Sprayed containment leakage:

| Bypass: | Air leakage | from: Sprayed | to: Environment |
| Annulus: | Air leakage | from: Sprayed | to: Annulus |

Unsprayed containment leakage:

| Bypass: | Air leakage | from: Unsprayed | to: Environment |
| Annulus: | Air leakage | from: Unsprayed | to: Annulus |

Containment mixing:

| Sprayed: | Air Leakage | from: Sprayed | to: Unsprayed |
| Unsprayed: | Air Leakage | from: Unsprayed | to: Sprayed |

Filter #1:	Filtered Pathway	from: Annulus	to: Environment
Filter #2:	Filtered Pathway	from: Environment	to: Control Room
CR exhaust:	Filtered Pathway	from: Control room	to: Environment
CR unfiltered inflow:	Filtered Pathway	from: Environment	to: Control Room

[All 10 transfer pathways are defined (name, from and to compartment, and transfer mechanism) on screen number 1410.]

Scenario Description

Containment mixing

Time (hr)	Sprayed to unsprayed (%/day)	Unsprayed to sprayed (%/day)
0.000	0.1053E+04	0.5555E+04
0.1667	0.4056E+04	0.2139E+05
0.500	0.4915E+04	2333E+05
1.175	0.2951E+04	0.1555E+05
1.800	0.1053E+04	0.5555E+04

Sprayed zone leak rate:

Time (hr)	Bypass rate (%/day)	Annulus rate (%/day)
0.0000	0.5000E-01	0.4500E+00
24.0000	0.2500E-01	0.2250E+00

Unsprayed zone leak rate:

Time (hr)	Bypass rate (%/day)	Annulus rate (%/day)
0.0000	0.5000E-01	0.4500E+00
24.0000	0.2500E-01	0.2250E+00

[All three sets of mixing flows use screen number 2440A.]

Spray removal coefficients:

Time (hr)	Aerosol and Elemental Removal Coefficients (hr^{-1})
0.00	1.50
0.50	12.0
1.80	5.00
2.00	2.00
8.00	0.40

Time (hr)	Organic Removal Coefficients
0.0	0.0

[Aerosols are on screen number 2311A, elementals on screen number 2312A, and organics are on screen number 2314A. Remember to set the Select User Parameters to Yes.]

Unsprayed zone aerosol natural deposition rate: $0.4167E-04 \ s^{-1}$

[Screen number 2341A; the values for elementals and organics will default to 0.0.]

Annulus exhaust:

Time (hr)	Filter #1 Flow rate (cfm)
0.0000	0.0000E+00
0.0278	0.1400E+05
0.2778	1.0000E+03

Filter #1 efficiencies:

Elemental iodine   0.0000%
Organic iodine   0.0000%
Aerosols   99.0000%

[screen number 2420A]

CR filter #2 flow rate: 0.2000E+04 cfm

CR filter #2 efficiencies:

Elemental iodine   95.0000%
Organic iodine   95.0000%
Aerosols   99.0000%

[screen number 2420A]

CR filter #3 flow rate: 0.4000E+04 cfm

CR filter #3 efficiencies:

Elemental iodine   95.0000%
Organic iodine   95.0000%
Aerosols   99.0000%

[screen number 2330A]

CR unfiltered inflow: 10 cfm

[This accounts for leakage into the room through doorways and other unfiltered leaks. All the efficiencies will be 0.0% for this example. Screen number 2420A.]

CR exhaust: 0.2010E+04 cfm

[This exhaust is through filters and will not affect the environmental dose. All the efficiencies are set at 100% for this example. Screen number 2420T.]

Dose Parameters

EAB X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.1100E-02
	2.0000	0.0000E+00

LPZ X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.5200E-04
	8.0000	0.3600E-04
	24.0000	0.1600E-04
	96.0000	0.5300E-05

Environmental breathing rates:	Time (hr)	Breathing Rate (m^3/s)
	0.0000	0.3470E-03
	8.0000	0.1750E-03
	24.0000	0.2320E-03

[The locations are on screen number 2520 & the values are on screen number 2523.]

CR filter X/Q values:	Time (hr)	X/Q (s/m$^{3)}$)
	0.0000	0.3320E-03
	8.0000	0.1960E-03
	24.0000	0.7640E-04
	96.0000	0.2190E-04

[These values are also used for the unfiltered inlets and are input on screen number 2420T2 with the efficiencies and flows.]

CR breathing rates:	Time (hr)	Breathing Rate (m^3/s)
	0.0000	0.3470E-03

CR occupancy factor:	Time (hr)	Occupancy Factor
	0.0000	1.000
	24.000	0.600
	96.0000	0.400

[The locations are on screen number 2520 and the values are on screen number 2522.]

1.6.3.2 *Example Problem 3 Output*

```
###############################################
#
            RADTRAD Version 2.12   06/12/97  21:29:27.44
#
###############################################
#
###############################################
#
                    File information
#
###############################################
#
Plant filename              = accept\test23.pmf
Inventory filename          = DEFAULTS\PWR_DEF.NIF
Scenario filename           = accept\test23.sdf
Release filename            = DEFAULTS\PWR_DBA.RFT
Dose conversion filename    = DEFAULTS\FGR60.INP
#
###############################################
#
###############################################
#
                   Plant Description
#
###############################################
#

Number of Nuclides = 60

Inventory Power =   0.1000E+01 MWth
Plant Power Level =   0.3992E+04 MWth

Number of compartments    =    5

Compartment information

Compartment number  1   (Source term compartment)
Name: Sprayed Region
Compartment volume =   0.2740E+07 (Cubic feet)
Removal devices within compartment:
    Spray(s)
Pathways into and out of compartment  1
    Pathway to compartment number    2: Sprayed to
Unsprayed
    Pathway to compartment number    3: Sprayed to Annulus
    Pathway to compartment number    4: Sprayed to
Environment
    Pathway from compartment number  2: Unsprayed to
Sprayed

Compartment number  2
Name: Unsprayed Region
Compartment volume =   0.6011E+06 (Cubic feet)
Removal devices within compartment:
    Deposition
Pathways into and out of compartment  2
    Pathway to compartment number    1: Unsprayed to
Sprayed
    Pathway to compartment number    3: Unsprayed to
Annulus
    Pathway to compartment number    4: Unsprayed to
Environment
    Pathway from compartment number  1: Sprayed to
Unsprayed

Compartment number  3
Name: Annulus
Compartment volume =   0.6162E+06 (Cubic feet)
Pathways into and out of compartment  3
    Pathway to compartment number    4: Annulus to
Environment
    Pathway from compartment number  1: Sprayed to Annulus
    Pathway from compartment number  2: Unsprayed to
Annulus

Compartment number  4
Name: Environment
Pathways into and out of compartment  4
    Pathway to compartment number    5: Filter 2--
Environment to CR
    Pathway to compartment number    5: Unfiltered--
Environment to CR
    Pathway from compartment number  1: Sprayed to
Environment
    Pathway from compartment number  2: Unsprayed to
Environment
    Pathway from compartment number  3: Annulus to
Environment
    Pathway from compartment number  5: Exhaust from CR to
Environment

Compartment number  5
Name: Control Room
Compartment volume =   0.6731E+05 (Cubic feet)
Removal devices within compartment:
    Filter(s)
```

Pathways into and out of compartment 5
   Pathway to compartment number 4: Exhaust from CR to
Environment
   Pathway from compartment number 4: Filter 2--
Environment to CR
   Pathway from compartment number 4: Unfiltered--
Environment to CR

Total number of pathways = 10

##
Scenario Description
#
##
#
#

Iodine fractions
   Aerosol   = 0.9500E+00
   Elemental = 0.4850E-01
   Organic   = 0.1500E-02

COMPARTMENT DATA

Compartment number 1: Sprayed Region

Sprays: Aerosol Removal Data
Time (hr)   DF (hr^-1)
0.0000E+00   0.1500E+01
0.5000E+00   0.1200E+02
0.1800E+01   0.5000E+01
0.2000E+01   0.2000E+01
0.8000E+01   0.4000E+00

Sprays: Elemental Removal Data
Time (hr)   DF (hr^-1)
0.0000E+00   0.1500E+01
0.5000E+00   0.1200E+02
0.1800E+01   0.5000E+01
0.2000E+01   0.2000E+01
0.8000E+01   0.4000E+00

Compartment number 2: Unsprayed Region

Natural Deposition: Aerosol data
Time (hr)   DF (hr^-1)
0.0000E+00   0.1500E+00
0.7200E+03   0.1500E+00

Compartment number 3: Annulus

Compartment number 4: Environment

Compartment number 5: Control Room

Compartment Filter Data

Flow rate = 0.4000E+04 (cfm)

                                Filter Efficiencies (%)
Time (hr)   Aerosol   Elemental   Organic
0.0000E+00
0.7200E+03
0.9500E+02   0.9900E+02   0.9500E+02   0.9500E+02
0.9500E+02   0.9900E+02

PATHWAY DATA

Pathway number 1: Sprayed to Unsprayed

   Convection Data
   Time (hr)   Flow Rate (% / day)
   0.0000E+00   0.1053E+04
   0.1667E+00   0.4056E+04
   0.5000E+00   0.4425E+04
   0.1175E+01   0.2951E+04
   0.1800E+01   0.1053E+04

Pathway number 2: Sprayed to Annulus

   Convection Data
   Time (hr)   Flow Rate (% / day)
   0.0000E+00   0.4500E+00
   0.2400E+02   0.2250E+00

Pathway number 3: Sprayed to Environment

   Convection Data
   Time (hr)   Flow Rate (% / day)
   0.0000E+00   0.5000E-01
   0.2400E+02   0.2500E-01

Pathway number 4: Unsprayed to Sprayed

   Convection Data
   Time (hr)   Flow Rate (% / day)
   0.0000E+00   0.4800E+04
   0.1667E+00   0.1845E+05
   0.5000E+00   0.2015E+05
   0.1175E+01   0.1344E+05
   0.1800E+01   0.4800E+04

Pathway number 5: Unsprayed to Annulus

Convection Data

Time (hr)	Flow Rate (% / day)
0.0000E+00	0.4500E+00
0.2400E+02	0.2250E+00

Pathway number 6: Unsprayed to Environment

Convection Data

Time (hr)	Flow Rate (% / day)
0.0000E+00	0.5000E-01
0.2400E+02	0.2500E-01

Pathway number 7: Annulus to Environment

Piping: Removal Data

Time (hr)	Flow Rate (cfm)	Aerosol	DF (s^-1) Elemental
Organic			
0.0000E+00	0.0000E+00	0.3600E+06	0.2778E-03
0.2778E-03			
0.2780E-01	0.1400E+05	0.3600E+06	0.2778E-03
0.2778E-03			
0.2778E+00	0.1000E+04	0.3600E+06	0.2778E-03
0.2778E-03			
0.7200E+03	0.1000E+04	0.3600E+06	0.2778E-03
0.2778E-03			

Pathway number 8: Filter 2--Environment to CR

Pathway Filter: Removal Data

Filter flow rate = 0.2000E+04 (cfm)

Time (hr)	Aerosol	Filter efficiency (%) Elemental
Organic		
0.0000E+00	0.9900E+02	0.9500E+02
0.9500E+02		
0.4800E+02	0.9900E+02	0.9500E+02
0.9500E+02		
0.7200E+02	0.9900E+02	0.9500E+02
0.9500E+02		
0.1200E+03	0.9900E+02	0.9500E+02
0.9500E+02		
0.2400E+03	0.9900E+02	0.9500E+02
0.9500E+02		

Pathway number 9: Unfiltered--Environment to CR

Pathway Filter: Removal Data

Filter flow rate = 0.1000E+02 (cfm)

Time (hr)	Aerosol	Filter efficiency (%) Elemental
Organic		
0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00		
0.7200E+03	0.0000E+00	0.0000E+00
0.0000E+00		

Pathway number 10: Exhaust from CR to Environment

Pathway Filter: Removal Data

Filter flow rate = 0.2010E+04 (cfm)

Time (hr)	Aerosol	Filter efficiency (%) Elemental
Organic		
0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00		
0.7200E+03	0.0000E+00	0.0000E+00
0.0000E+00		

LOCATION DATA
Location Exclusion Area Boundary   is in compartment   4

Location X/Q Data

Time (hr)	X/Q (s * m^-3)
0.0000E+00	0.1000E-02
0.2000E+01	0.0000E+00

Location Breathing Rate Data

Time (hr)	Breathing Rate (m^3 * sec^-1)
0.0000E+00	0.3470E-03
0.8000E+01	0.1750E-03
0.2400E+02	0.2320E-03

Location Low Population Zone   is in compartment   4

Location X/Q Data

Time (hr)	X/Q (s * m^-3)
0.0000E+00	0.1350E-03
0.8000E+01	0.1000E-03
0.2400E+02	0.5400E-04
0.9600E+02	0.2200E-04

Location Breathing Rate Data
Time (hr)   Breathing Rate (m^3 * sec^-1)

```
                              0.0000E+00       0.3470E-03
                              0.8000E+01       0.1750E-03
                              0.2400E+02       0.2320E-03
Location Control Room        is in compartment    5

Location Breathing Rate Data
Time (hr)       Breathing Rate (m^3 * sec^-1)
0.0000E+00       0.3470E-03
0.7200E+03       0.0000E+00

Location Occupancy Factor Data
Time (hr)       Occupancy Factor
0.0000E+00       0.1000E+01
0.2400E+02       0.6000E+00
0.9600E+02       0.4000E+00
0.7200E+03       0.0000E+00

USER SPECIFIED TIME STEP DATA - SUPPLEMENTAL TIME STEPS
Time            Time step
0.0000E+00       0.2500E+00
0.4000E+01       0.1000E+01
0.2400E+02       0.4000E+01
0.7200E+03       0.0000E+00

###########################################################
##########
Output        Dose, Detailed model and Detailed Inventory
###########################################################
##########
```

Exclusion Area Boundary Doses:

Time (h) = 0.0278	Whole Body	Thyroid	TEDE
Delta dose (rem)	0.2561E-03	0.4311E-01	0.1863E-02
Accumulated dose (rem)	0.2561E-03	0.4311E-01	0.1863E-02

Low Population Zone Doses:

Time (h) = 0.0278	Whole Body	Thyroid	TEDE
Delta dose (rem)	0.3458E-04	0.5819E-02	0.2515E-03
Accumulated dose (rem)	0.3458E-04	0.5819E-02	0.2515E-03

Control Room Doses:

Time (h) = 0.0278	Whole Body	Thyroid	TEDE
Delta dose (rem)	0.8371E-07	0.3803E-04	0.1476E-05
Accumulated dose (rem)	0.8371E-07	0.3803E-04	0.1476E-05

Annulus Atmosphere Nuclide Inventory:

Time (h) = 0.0278

	Bq	Atoms	kg	Ci
Kr-85	0.2098E+09	0.1024E+18	0.1445E-07	0.5669E-02
Kr-85m	0.9825E+10	0.2286E+15	0.3227E-10	0.2655E+00
Kr-87	0.1796E+11	0.1186E+15	0.1713E-10	0.4853E+00
Kr-88	0.2428E+11	0.3582E+15	0.5234E-10	0.6563E+00
Rb-86	0.1579E+08	0.3673E+14	0.5245E-11	0.4268E-03
I-131	0.2681E+11	0.2687E+17	0.5845E-08	0.7246E+00
I-132	0.3951E+11	0.4719E+15	0.1034E-09	0.1068E+01
I-133	0.5668E+11	0.6123E+16	0.1352E-08	0.1532E+01
I-134	0.6220E+11	0.2832E+15	0.6302E-10	0.1681E+01
I-135	0.5344E+11	0.1835E+16	0.4113E-09	0.1444E+01
Xe-133	0.5749E+11	0.3759E+17	0.8301E-08	0.1554E+01
Xe-135	0.1079E+11	0.5093E+15	0.1142E-09	0.2915E+00
Cs-134	0.3615E+10	0.3394E+18	0.7552E-07	0.9770E-01
Cs-136	0.1100E+10	0.1796E+16	0.4056E-09	0.2972E-01
Cs-137	0.2021E+10	0.2761E+19	0.6280E-06	0.5463E-01

Annulus Transport Group Inventory:

Time (h) = 0.0278	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	0.1412E+18	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.1726E+16	0.0000E+00	0.0000E+00
Organic I (atoms)	0.5411E+14	0.0000E+00	0.0000E+00
Aerosols (kg)	0.7114E-06	0.0000E+00	0.0000E+00

Time (h) = 0.0278	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	^.0000E+00
Elemental I (atoms)	0.0000E+00	0.0000E+00
Organic I (atoms)	0.0000E+00	0.0000E+00
Aerosols (kg)	0.0000E+00	0.0000E+00

Annulus to Environment Transport Group Inventory:

```
Time (h) =    0.0278    Pipe Walls
Noble gases (atoms)     0.0000E+00
Elemental I (atoms)     0.0000E+00
Organic I (atoms)       0.0000E+00
Aerosols (kg)           0.0000E+00
```

Environment Atmosphere Nuclide Inventory:

Time (h) = 0.0278	Atoms	kg	Ci
Bq			
Kr-85			
0.2331E+08	0.1137E+17	0.1606E-08	0.6299E-03
Kr-85m			
0.1092E+10	0.2540E+14	0.3585E-11	0.2951E-01
Kr-87			
0.1995E+10	0.1318E+14	0.1904E-11	0.5393E-01
Kr-88			
0.2698E+10	0.3980E+14	0.5815E-11	0.7292E-01
Rb-86			
0.1754E+07	0.4081E+13	0.5828E-12	0.4742E-04
I-131			
0.2979E+10	0.2985E+16	0.6494E-09	0.8051E-01
I-132			
0.4390E+10	0.5244E+14	0.1149E-10	0.1186E+00
I-133			
0.6298E+10	0.6804E+15	0.1503E-09	0.1702E+00
I-134			
0.6911E+10	0.3147E+14	0.7002E-11	0.1868E+00
I-135			
0.5938E+10	0.2038E+15	0.4570E-10	0.1605E+00
Xe-133			
0.6388E+10	0.4176E+16	0.9223E-09	0.1726E+00
Xe-135			
0.1199E+10	0.5659E+14	0.1269E-10	0.3239E-01
Cs-134			
0.4017E+09	0.3771E+17	0.8391E-08	0.1086E-01
Cs-136			
0.1222E+09	0.1995E+15	0.4506E-10	0.3303E-02
Cs-137			
0.2246E+09	0.3067E+18	0.6978E-07	0.6070E-02

Environment Atmosphere Nuclide Release Rates:

Time (h) = 0.0278	Atoms/s	kg/s	Ci/s
Bq/s			
Kr-85			
0.2329E+06	0.1137E+15	0.1604E-10	0.6294E-05
Kr-85m			
0.1091E+08	0.2538E+12	0.3582E-13	0.2948E-03
Kr-87			
0.1994E+08	0.1317E+12	0.1902E-13	0.5388E-03
Kr-88			
0.2696E+08	0.3976E+12	0.5811E-13	0.7286E-03
Rb-86			
0.1753E+05	0.4078E+11	0.5823E-14	0.4738E-06
I-131			
0.2977E+08	0.2983E+14	0.6489E-11	0.8045E-03
I-132			
0.4386E+08	0.5240E+12	0.1148E-12	0.1185E-02
I-133			
0.6293E+08	0.6798E+13	0.1501E-11	0.1701E-02
I-134			
0.6906E+08	0.3144E+12	0.6996E-13	0.1866E-02
I-135			
0.5933E+08	0.2037E+13	0.4566E-12	0.1604E-02
Xe-133			
0.6383E+08	0.4173E+14	0.9216E-11	0.1725E-02
Xe-135			
0.1198E+08	0.5654E+12	0.1268E-12	0.3237E-03
Cs-134			
0.4014E+07	0.3768E+15	0.8384E-10	0.1085E-03
Cs-136			
0.1221E+07	0.1994E+13	0.4503E-12	0.3300E-04
Cs-137			
0.2244E+07	0.3065E+16	0.6973E-09	0.6065E-04

Environment Transport Group Inventory:

Time (h) = 0.0278	Present Release	Release Rate/s	Total Release
Noble gases (atoms)	0.1569E+17	0.1567E+15	0.1569E+17
Elemental I (atoms)	0.1917E+15	0.1916E+13	0.1917E+15
Organic I (atoms)	0.6013E+13	0.6008E+11	0.6013E+13
Aerosols (kg)	0.7904E-07	0.7898E-09	0.7904E-07

Annulus to Environment Transport Group Inventory:

```
Time (h) =    0.0278    Pipe Walls
Noble gases (atoms)     0.0000E+00
Elemental I (atoms)     0.0000E+00
Organic I (atoms)       0.0000E+00
Aerosols (kg)           0.0000E+00
```

Filter 2--Environment to CR Transport Group Inventory:

```
                        Pathway
Time (h) =    0.0278    Filter
Noble gases (atoms)     0.0000E+00
Elemental I (atoms)     0.5736E+16
Organic I (atoms)       0.1799E+15
Aerosols (kg)           0.2464E-05
```

Unfiltered--Environment to CR Transport Group Inventory:

Control Room Transport Group Inventory:

Time (h) = 0.0278	Atmosphere	Sump	Overlying Pool
Noble gases (atoms)	0.3220E+14	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.2088E+11	0.0000E+00	0.0000E+00
Organic I (atoms)	0.6549E+09	0.0000E+00	0.0000E+00
Aerosols (kg)	0.2345E-11	0.0000E+00	0.0000E+00

Time (h) = 0.0278	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.0000E+00	0.6554E+09
Organic I (atoms)	0.0000E+00	0.2056E+08
Aerosols (kg)	0.0000E+00	0.7669E-13

Filter 2--Environment to CR Transport Group Inventory:

Time (h) = 0.0278	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.5736E+16
Organic I (atoms)	0.1799E+15
Aerosols (kg)	0.2464E-05

Unfiltered--Environment to CR Transport Group Inventory:

Time (h) = 0.0278	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Exhaust from CR to Environment Transport Group Inventory:

Time (h) = 0.0278	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

*** Intermediate time steps not edited ***

Exhaust from CR to Environment Transport Group Inventory:

Time (h) = 0.0278	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Control Room Atmosphere Nuclide Inventory:

Time (h) = 0.0278

Nuclide	Atoms	kg	Ci	Bq
Kr-85	0.2335E+14	0.3296E-11	0.1293E-05	0.4784E+05
Kr-85m	0.5214E+11	0.7360E-14	0.6057E-04	0.2241E+07
Kr-87	0.2705E+11	0.3908E-14	0.1107E-03	0.4096E+07
Kr-88	0.8169E+11	0.1194E-13	0.1497E-03	0.5538E+07
Rb-86	0.1210E+09	0.1729E-16	0.1407E-08	0.5204E+02
I-131	0.1004E+12	0.2184E-13	0.2707E-05	0.1002E+06
I-132	0.1763E+10	0.3865E-15	0.3989E-05	0.1476E+06
I-133	0.2288E+11	0.5053E-14	0.5724E-05	0.2118E+06
I-134	0.1058E+10	0.2355E-15	0.6281E-05	0.2324E+06
I-135	0.6855E+10	0.1537E-14	0.5396E-05	0.1997E+06
Xe-133	0.8573E+13	0.1893E-11	0.3544E-03	0.1311E+08
Xe-135	0.1162E+12	0.2604E-13	0.6650E-04	0.2460E+07
Cs-134	0.1119E+13	0.2489E-12	0.3220E-06	0.1191E+05
Cs-136	0.5919E+10	0.1337E-14	0.9797E-07	0.3625E+04
Cs-137	0.9099E+13	0.2070E-11	0.1800E-06	0.6662E+04

Exclusion Area Boundary Doses:

Time (h) = 720.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	0.0000E+00	0.0000E+00	0.0000E+00
Accumulated dose (rem)	0.1630E+01	0.6173E+02	0.4158E+01

Low Population Zone Doses:

Time (h) = 720.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	0.5080E+02	0.2264E+02	0.5151E+02
Accumulated dose (rem)	0.1038E+03	0.5810E+02	0.1057E+03

Control Room Doses:

Time (h) = 720.0000	Whole Body	Thyroid	TEDE
Delta dose (rem)	0.1614E+02	0.5596E+01	0.1632E+02
Accumulated dose (rem)	0.3573E+02	0.1408E+02	0.3618E+02

Annulus Atmosphere Nuclide Inventory:

Time (h) = 720.0000	Atoms	kg	Ci	Bq
Co-58	0.8394E-14	0.8084E-39	0.2571E-31	0.9511E-21
Co-60	0.1746E-12	0.1740E-37	0.1966E-31	0.7276E-21
Kr-85	0.1261E+23	0.1779E-02	0.6981E+03	0.2583E+14
Kr-85m	0.2815E+20	0.3973E-05	0.3270E+05	0.1210E+16
Kr-87	0.1460E+20	0.2110E-05	0.5976E+05	0.2211E+16
Kr-88	0.4410E+20	0.6445E-05	0.8081E+05	0.2990E+16
Rb-86	0.1798E-13	0.2567E-38	0.2089E-30	0.7729E-20
Sr-89	0.5336E-11	0.7886E-36	0.2291E-28	0.8476E-18
Sr-90	0.6065E-10	0.9065E-35	0.1236E-29	0.4575E-19
Sr-91	0.5376E-13	0.8124E-38	0.2945E-28	0.1090E-17
Sr-92	0.1596E-13	0.2438E-38	0.3065E-28	0.1134E-17
Y-90	0.1632E-15	0.2439E-40	0.1327E-31	0.4909E-21
Y-91	0.7532E-21	0.1138E-37	0.2791E-30	0.1033E-19
Y-92	0.2093E-15	0.3197E-40	0.3076E-30	0.1138E-19
Y-93	0.6754E-15	0.1043E-39	0.3480E-30	0.1288E-19
Zr-95	0.1040E-12	0.1641E-37	0.3526E-30	0.1305E-19
Zr-97	0.1193E-14	0.1922E-39	0.3675E-30	0.1360E-19
Nb-95	0.5404E-13	0.8524E-38	0.3333E-30	0.1233E-19
Mo-99	0.6168E-13	0.1014E-37	0.4863E-29	0.1799E-18
Tc-99m	0.4856E-14	0.7983E-39	0.4198E-29	0.1553E-18
Ru-103	0.6563E-12	0.1123E-36	0.3623E-29	0.1340E-18
Ru-105	0.2010E-14	0.3505E-39	0.2356E-29	0.8718E-19
Ru-106	0.1398E-11	0.2460E-36	0.8231E-30	0.3046E-19
Rh-105	0.1109E-13	0.1934E-38	0.1632E-29	0.6039E-19
Sb-127	0.7895E-13	0.1665E-37	0.4447E-29	0.1645E-18
Sb-129	0.1307E-13	0.2800E-38	0.1575E-28	0.5827E-18
Te-127	0.7714E-14	0.1627E-38	0.4293E-29	0.1589E-18
Te-127m	0.2858E-12	0.6027E-37	0.5685E-30	0.2103E-19
Te-129	0.3295E-14	0.7059E-39	0.1478E-28	0.5470E-18
Te-129m	0.6039E-12	0.1294E-36	0.3897E-29	0.1442E-18
Te-131m	0.4304E-13	0.9362E-38	0.7465E-29	0.2762E-18
Te-132	0.1117E-11	0.2448E-36	0.7431E-28	0.2749E-17
I-131	0.2013E+19	0.4378E-06	0.5428E+02	0.2008E+13
I-132	0.3535E+17	0.7749E-08	0.7998E+02	0.2959E+13
I-133	0.4587E+18	0.1013E-06	0.1148E+03	0.4246E+13
I-134	0.2121E+17	0.4721E-08	0.1259E+03	0.4659E+13
I-135	0.1374E+18	0.3081E-07	0.1082E+03	0.4003E+13
Xe-133	0.4628E+22	0.1022E-02	0.1913E+06	0.7079E+16
Xe-135	0.6271E+20	0.1406E-04	0.3590E+05	0.1328E+16
Cs-134	0.1661E-09	0.3697E-34	0.4783E-28	0.1770E-17

Noble gases (atoms) 0.0000E+00 0.0000E+00
Elemental I (atoms) 0.0000E+00 0.0000E+00
Organic I (atoms)   0.0000E+00 0.0000E+00
Aerosols   (kg)   0.0000E+00 0.0000E+00

Annulus to Environment Transport Group Inventory:

Time (h) = 720.0000

	Pipe Walls
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.2193E+12
Organic I (atoms)	0.1578E+14
Aerosols (kg)	0.8976E-03

Environment Atmosphere Nuclide Inventory:

Time (h) = 720.0000

	Bq	Atoms	kg	Ci
Co-58	0.1889E-02	0.1667E+05	0.1606E-20	0.5107E-13
Co-60	0.1445E-02	0.3469E+06	0.3456E-19	0.3906E-13
Kr-85	0.1376E+16	0.6715E+24	0.9478E-01	0.3719E+05
Kr-85m	0.6445E+17	0.1500E+22	0.2117E-03	0.1742E+07
Kr-87	0.1178E+18	0.7780E+21	0.1124E-03	0.3184E+07
Kr-88	0.1593E+18	0.2349E+22	0.3433E-03	0.4305E+07
Rb-86	0.1535E-01	0.3571E+05	0.5100E-20	0.4150E-12
Sr-89	0.1684E+01	0.1060E+08	0.1566E-17	0.4551E-10
Sr-90	0.9088E-01	0.1205E+09	0.1801E-16	0.2456E-11
Sr-91	0.2165E+01	0.1068E+06	0.1614E-19	0.5850E-10
Sr-92	0.2253E+01	0.3171E+05	0.4844E-20	0.6089E-10
Y-90	0.9751E-03	0.3241E+03	0.4844E-22	0.2635E-13
Y-91	0.2052E-01	0.1496E+06	0.2261E-19	0.5545E-12
Y-92	0.2261E-01	0.4157E+03	0.6351E-22	0.6111E-12
Y-93	0.2558E-01	0.1342E+04	0.2072E-21	0.6913E-12
Zr-95	0.2591E-01	0.2067E+06	0.3260E-19	0.7004E-12
Zr-97	0.2701E-01	0.2371E+04	0.3819E-21	0.7300E-12
Cs-136	0.5384E-18	0.8791E-12	0.1985E-36	0.1455E-28
Cs-137	0.9894E-18	0.1351E-08	0.3074E-33	0.2674E-28
Ba-139	0.1483E-17	0.1062E-13	0.2451E-38	0.4008E-28
Ba-140	0.1468E-17	0.2331E-11	0.5418E-36	0.3966E-28
La-140	0.1500E-19	0.3137E-14	0.7293E-39	0.4053E-30
La-141	0.1375E-19	0.2808E-15	0.6573E-40	0.3718E-30
La-142	0.1326E-19	0.1062E-15	0.2504E-40	0.3584E-30
Ce-141	0.3335E-19	0.1351E-12	0.3163E-37	0.9014E-30
Ce-143	0.3243E-19	0.5558E-14	0.1320E-38	0.8764E-30
Ce-144	0.2010E-19	0.7121E-12	0.1703E-36	0.5431E-30
Pr-143	0.1274E-19	0.2153E-13	0.5111E-38	0.3442E-30
Nd-147	0.5696E-20	0.7795E-14	0.1903E-38	0.1539E-30
Np-239	0.3815E-18	0.1120E-12	0.4444E-37	0.1031E-28
Pu-238	0.2162E-22	0.8638E-13	0.3414E-37	0.5844E-33
Pu-239	0.4877E-23	0.5343E-11	0.2121E-35	0.1318E-33
Pu-240	0.6150E-23	0.1830E-11	0.7295E-36	0.1662E-33
Pu-241	0.1036E-20	0.6790E-12	0.2717E-36	0.2799E-31
Am-241	0.2736E-24	0.5384E-14	0.2155E-38	0.7396E-35
Cm-242	0.1047E-21	0.2125E-14	0.8541E-39	0.2831E-32
Cm-244	0.6128E-23	0.5052E-14	0.2047E-38	0.1656E-33

Annulus Transport Group Inventory:

Time (h) = 720.0000

	Atmosphere	Sump	Overlying Pool	Deposition Surfaces	Recirculating Filter
Noble gases (atoms)	0.1738E+23	0.0000E+00	0.0000E+00		
Elemental I (atoms)	0.1112E-11	0.0000E+00	0.0000E+00		
Organic I (atoms)	0.2665E+19	0.0000E+00	0.0000E+00		
Aerosols (kg)	0.3640E-33	0.0000E+00	0.0000E+00		

Time (h) = 720.0000

Nb-95	0.2450E-01	0.1073E+06	0.1693E-19	0.6622E-12
Mo-99	0.3575E+00	0.1225E+06	0.2014E-19	0.9661E-11
Tc-99m	0.3085E+00	0.9647E+04	0.1586E-20	0.8339E-11
Ru-103	0.2663E+00	0.1304E+07	0.2230E-18	0.7197E-11
Ru-105	0.1732E+00	0.3994E+04	0.6963E-21	0.4681E-11
Ru-106	0.6050E-01	0.2777E+07	0.4888E-18	0.1635E-11
Rh-105	0.1200E+00	0.2203E+05	0.3841E-20	0.3242E-11
Sb-127	0.3268E+00	0.1568E+06	0.3308E-19	0.8833E-11
Sb-129	0.1157E+01	0.2597E+05	0.5563E-20	0.3128E-10
Te-127	0.3156E+00	0.1532E+05	0.3232E-20	0.8529E-11
Te-127m	0.4178E-01	0.5677E+06	0.1197E-18	0.1129E-11
Te-129	0.1087E+01	0.6546E+04	0.1402E-20	0.2937E-10
Te-129m	0.2864E+00	0.1200E+07	0.2570E-18	0.7741E-11
Te-131m	0.5487E+00	0.8549E+05	0.1860E-19	0.1483E-10
Te-132	0.5462E+01	0.2218E+07	0.4862E-18	0.1476E-09
I-131	0.1069E+15	0.1072E+21	0.2331E-04	0.2890E+04
I-132	0.1576E+15	0.1882E+19	0.4126E-06	0.4259E+04
I-133	0.2261E+15	0.2442E+20	0.5394E-05	0.6110E+04
I-134	0.2481E+15	0.1130E+19	0.2514E-06	0.6705E+04
I-135	0.2132E+15	0.7318E+19	0.1640E-05	0.5761E+04
Xe-133	0.3771E+18	0.2465E+24	0.5445E-01	0.1019E+08
Xe-135	0.7076E+17	0.3341E+22	0.7489E-03	0.1912E+07
Cs-134	0.3515E+01	0.3300E+09	0.7343E-16	0.9501E-10
Cs-136	0.1069E+01	0.1746E+07	0.3944E-18	0.2890E-10
Cs-137	0.1965E+01	0.2685E+10	0.6107E-15	0.5312E-10
Ba-139	0.2946E+01	0.2109E+05	0.4868E-20	0.7962E-10

Ba-140	0.2915E+01	0.4630E+07	0.1076E-17	0.7879E-10
La-140	0.2979E-01	0.6231E+04	0.1449E-20	0.8052E-12
La-141	0.2732E-01	0.5577E+03	0.1306E-21	0.7385E-12
La-142	0.2634E-01	0.2109E+03	0.4973E-22	0.7119E-12
Ce-141	0.6625E-01	0.2684E+06	0.6284E-19	0.1791E-11
Ce-143	0.6442E-01	0.1104E+05	0.2622E-20	0.1741E-11
Ce-144	0.3992E-01	0.1415E+07	0.3383E-18	0.1079E-11
Pr-143	0.2530E-01	0.4276E+05	0.1015E-19	0.6838E-12
Nd-147	0.1131E-01	0.1549E+05	0.3780E-20	0.3058E-12
Np-239	0.7578E+00	0.2225E+06	0.8829E-19	0.2048E-10
Pu-238	0.4295E-04	0.1716E+06	0.6781E-19	0.1161E-14
Pu-239	0.9688E-05	0.1061E+08	0.4212E-17	0.2618E-15
Pu-240	0.1222E-04	0.3636E+07	0.1449E-17	0.3302E-15
Pu-241	0.2057E-02	0.1349E+07	0.5398E-18	0.5561E-13
Am-241	0.5436E-06	0.1070E+05	0.4280E-20	0.1469E-16
Cm-242	0.2081E-03	0.4222E+04	0.1697E-20	0.5623E-14
Cm-244	0.1217E-04	0.1004E+05	0.4067E-20	0.3290E-15

Environment Atmosphere Nuclide Release Rates:

Time (h) = 720.0000

	Bq/s	Atoms/s	kg/s	Ci/s
Co-58	0.1093E-08	0.9650E-02	0.9294E-27	0.2955E-19
Co-60	0.8364E-09	0.2007E+00	0.2000E-25	0.2261E-19
Kr-85	0.7962E+09	0.3886E+18	0.5485E-07	0.2152E-01
Kr-85m	0.3730E+11	0.8678E+15	0.1225E-09	0.1008E+01
Kr-87	0.6817E+11	0.4502E+15	0.6504E-10	0.1842E+01
Kr-88	0.9218E+11	0.1360E+16	0.1987E-09	0.2491E+01

Nuclide				
Rb-86	0.8886E-08	0.2067E-01	0.2951E-26	0.2402E-18
Sr-89	0.9744E-06	0.6134E+01	0.9065E-24	0.2634E-16
Sr-90	0.5259E-07	0.6973E+02	0.1042E-22	0.1421E-17
Sr-91	0.1253E-05	0.6181E-01	0.9339E-26	0.3386E-16
Sr-92	0.1304E-05	0.1835E-01	0.2803E-26	0.3524E-16
Y-90	0.5643E-09	0.1876E-03	0.2803E-28	0.1525E-19
Y-91	0.1187E-07	0.8659E-01	0.1308E-25	0.3209E-18
Y-92	0.1309E-07	0.2406E-03	0.3675E-28	0.3536E-18
Y-93	0.1480E-07	0.7764E-03	0.1199E-27	0.4000E-18
Zr-95	0.1500E-07	0.1196E+00	0.1887E-25	0.4053E-18
Zr-97	0.1563E-07	0.1372E-02	0.2210E-27	0.4225E-18
Nb-95	0.1418E-07	0.6212E-01	0.9799E-26	0.3832E-18
Mo-99	0.2069E-06	0.7091E-01	0.1166E-25	0.5591E-17
Tc-99m	0.1786E-06	0.5583E-02	0.9178E-27	0.4826E-17
Ru-103	0.1541E-06	0.7545E+00	0.1290E-24	0.4165E-17
Ru-105	0.1002E-06	0.2311E-02	0.4029E-27	0.2709E-17
Ru-106	0.3501E-07	0.1607E+01	0.2828E-24	0.9463E-18
Rh-105	0.6943E-07	0.1275E-01	0.2223E-26	0.1876E-17
Sb-127	0.1891E-06	0.9076E-01	0.1914E-25	0.5112E-17
Sb-129	0.6698E-06	0.1503E-01	0.3219E-26	0.1810E-16
Te-127	0.1826E-06	0.8868E-02	0.1870E-26	0.4936E-17
Te-127m	0.2418E-07	0.3285E+00	0.6929E-25	0.6535E-18
Te-129	0.6288E-06	0.3788E-02	0.8115E-27	0.1699E-16
Te-129m	0.1657E-06	0.6942E+00	0.1487E-24	0.4480E-17
Te-131m	0.3175E-06	0.4948E-01	0.1076E-25	0.8582E-17
Te-132	0.3161E-05	0.1284E+01	0.2814E-24	0.8543E-16

Nuclide				
I-131	0.6188E+08	0.6202E+14	0.1349E-10	0.1673E-02
I-132	0.9119E+08	0.1089E+13	0.2388E-12	0.2465E-02
I-133	0.1308E+09	0.1413E+14	0.3121E-11	0.3536E-02
I-134	0.1436E+09	0.6537E+12	0.1455E-12	0.3880E-02
I-135	0.1234E+09	0.4235E+13	0.9493E-12	0.3334E-02
Xe-133	0.2182E+12	0.1427E+18	0.3151E-07	0.5898E+01
Xe-135	0.4095E+11	0.1933E+16	0.4334E-09	0.1107E+01
Cs-134	0.2034E-05	0.1910E+03	0.4250E-22	0.5498E-16
Cs-136	0.6189E-06	0.1011E+01	0.2282E-24	0.1673E-16
Cs-137	0.1137E-05	0.1554E+04	0.3534E-21	0.3074E-16
Ba-139	0.1705E-05	0.1220E-01	0.2817E-26	0.4608E-16
Ba-140	0.1687E-05	0.2679E+01	0.6228E-24	0.4560E-16
La-140	0.1724E-07	0.3606E-02	0.8383E-27	0.4660E-18
La-141	0.1581E-07	0.3228E-03	0.7557E-28	0.4274E-18
La-142	0.1524E-07	0.1221E-03	0.2878E-28	0.4120E-18
Ce-141	0.3834E-07	0.1553E+00	0.3637E-25	0.1036E-17
Ce-143	0.3728E-07	0.6389E-02	0.1517E-26	0.1008E-17
Ce-144	0.2310E-07	0.8187E+00	0.1958E-24	0.6244E-18
Pr-143	0.1464E-07	0.2475E-01	0.5876E-26	0.3957E-18
Nd-147	0.6548E-08	0.8961E-02	0.2187E-26	0.1770E-18
Np-239	0.4386E-06	0.1287E+00	0.5109E-25	0.1185E-16
Pu-238	0.2486E-10	0.9930E-01	0.3924E-25	0.6718E-21
Pu-239	0.5606E-11	0.6142E+01	0.2438E-23	0.1515E-21
Pu-240	0.7070E-11	0.2104E+01	0.8386E-24	0.1911E-21
Pu-241	0.1191E-08	0.7806E+00	0.3124E-24	0.3218E-19
Am-241	0.3146E-12	0.6190E-02	0.2477E-26	0.8502E-23

Cm-242   0.1204E-09   0.2443E-02   0.9818E-27   0.3254E-20
Cm-244   0.7044E-11   0.5808E-02   0.2353E-26   0.1904E-21

Environment Transport Group Inventory:

Time (h) = 720.0000

	Present Release	Release Rate/s	Total Release
Noble gases (atoms)	0.9260E+24	0.5359E+18	0.1432E+25
Elemental I (atoms)	0.2209E+09	0.1279E+03	0.3045E+19
Organic I (atoms)	0.1419E+21	0.8213E+14	0.2195E+21
Aerosols (kg)	0.7230E-15	0.4184E-21	0.1097E-03

Annulus to Environment Transport Group Inventory:

Time (h) = 720.0000

	Pipe Walls
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.2193E+12
Organic I (atoms)	0.1578E+14
Aerosols (kg)	0.8976E-03

Filter 2--Environment to CR Transport Group Inventory:

Time (h) = 720.0000

	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.5389E+22
Organic I (atoms)	0.1374E+25
Aerosols (kg)	0.5732E-01

Unfiltered--Environment to CR Transport Group Inventory:

Time (h) = 720.0000

	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Exhaust from CR to Environment Transport Group Inventory:

Time (h) = 720.0000

	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Control Room Atmosphere Nuclide Inventory:

Time (h) = 720.0000

	Bq	Atoms	kg	Ci
Co-58	0.1205E-29	0.1063E-22	0.1024E-47	0.3256E-40
Co-60	0.9216E-30	0.2212E-21	0.2204E-46	0.2491E-40
Kr-85	0.7105E+09	0.3467E+18	0.4894E-07	0.1920E-01
Kr-85m	0.3328E+11	0.7743E+15	0.1093E-09	0.8994E+00
Kr-87	0.6082E+11	0.4017E+15	0.5804E-10	0.1644E+01
Kr-88	0.8225E+11	0.1213E+16	0.1773E-09	0.2223E+01
Rb-86	0.9791E-29	0.2277E-22	0.3252E-47	0.2646E-39
Sr-89	0.1074E-26	0.6759E-20	0.9988E-45	0.2902E-37
Sr-90	0.5795E-28	0.7683E-19	0.1148E-43	0.1566E-38
Sr-91	0.1380E-26	0.6810E-22	0.1029E-46	0.3730E-37
Sr-92	0.1436E-26	0.2022E-22	0.3089E-47	0.3882E-37
Y-90	0.6218E-30	0.2067E-24	0.3089E-49	0.1680E-40
Y-91	0.1308E-28	0.9540E-22	0.1442E-46	0.3535E-39
Y-92	0.1442E-28	0.2651E-24	0.4050E-49	0.3897E-39
Y-93	0.1631E-28	0.8555E-24	0.1321E-48	0.4408E-39
Zr-95	0.1652E-28	0.1318E-21	0.2079E-46	0.4466E-39
Zr-97	0.1722E-28	0.1512E-23	0.2435E-48	0.4655E-39
Nb-95	0.1562E-28	0.6845E-22	0.1080E-46	0.4222E-39
Mo-99	0.2279E-27	0.7813E-22	0.1284E-46	0.6160E-38
Tc-99m	0.1967E-27	0.6151E-23	0.1011E-47	0.5317E-38
Ru-103	0.1698E-27	0.8313E-21	0.1422E-45	0.4589E-38
Ru-105	0.1104E-27	0.2546E-23	0.4440E-48	0.2984E-38
Ru-106	0.3858E-28	0.1771E-20	0.3116E-45	0.1043E-38
Rh-105	0.7650E-28	0.1405E-22	0.2449E-47	0.2067E-38
Sb-127	0.2084E-27	0.1000E-21	0.2109E-46	0.5632E-38

Isotope inventory (continued):

Isotope				
Sb-129	0.7381E-27	0.1656E-22	0.3547E-47	0.1995E-37
Te-127	0.2012E-27	0.9771E-23	0.2061E-47	0.5438E-38
Te-127m	0.2664E-28	0.3620E-21	0.7634E-46	0.7201E-39
Te-129	0.6928E-27	0.4174E-23	0.8942E-48	0.1873E-37
Te-129m	0.1826E-27	0.7649E-21	0.1638E-45	0.4936E-38
Te-131m	0.3499E-27	0.5451E-22	0.1186E-46	0.9456E-38
Te-132	0.3483E-26	0.1414E-20	0.3100E-45	0.9413E-37
I-131	0.1045E+07	0.1048E+13	0.2279E-12	0.2825E-04
I-132	0.1540E+07	0.1840E+11	0.4034E-14	0.4163E-04
I-133	0.2210E+07	0.2388E+12	0.5273E-13	0.5973E-04
I-134	0.2425E+07	0.1104E+11	0.2457E-14	0.6555E-04
I-135	0.2084E+07	0.7154E+11	0.1604E-13	0.5632E-04
Xe-133	0.1947E+12	0.1273E+18	0.2812E-07	0.5263E+01
Xe-135	0.3654E+11	0.1725E+16	0.3867E-09	0.9875E+00
Cs-134	0.2241E-26	0.2104E-18	0.4682E-43	0.6058E-37
Cs-136	0.6819E-27	0.1114E-20	0.2515E-45	0.1843E-37
Cs-137	0.1253E-26	0.1712E-17	0.3894E-42	0.3387E-37
Ba-139	0.1879E-26	0.1345E-22	0.3104E-47	0.5077E-37
Ba-140	0.1859E-26	0.2952E-20	0.6863E-45	0.5024E-37
La-140	0.1900E-28	0.3973E-23	0.9237E-48	0.5134E-39
La-141	0.1742E-28	0.3556E-24	0.8326E-49	0.4709E-39
La-142	0.1680E-28	0.1345E-24	0.3171E-49	0.4539E-39
Ce-141	0.4224E-28	0.1711E-21	0.4007E-46	0.1142E-38
Ce-143	0.4107E-28	0.7040E-23	0.1672E-47	0.1110E-38
Ce-144	0.2545E-28	0.9020E-21	0.2157E-45	0.6880E-39
Pr-143	0.1613E-28	0.2727E-22	0.6475E-47	0.4360E-39
Nd-147	0.7214E-29	0.9874E-23	0.2410E-47	0.1950E-39
Np-239	0.4832E-27	0.1419E-21	0.5630E-46	0.1306E-37
Pu-238	0.2739E-31	0.1094E-21	0.4324E-46	0.7402E-42
Pu-239	0.6177E-32	0.6768E-20	0.2686E-44	0.1670E-42
Pu-240	0.7790E-32	0.2318E-20	0.9240E-45	0.2105E-42
Pu-241	0.1312E-29	0.8601E-21	0.3442E-45	0.3546E-40
Am-241	0.3466E-33	0.6820E-23	0.2729E-47	0.9368E-44
Cm-242	0.1327E-30	0.2692E-23	0.1082E-47	0.3585E-41
Cm-244	0.7762E-32	0.6400E-23	0.2593E-47	0.2098E-42

Control Room Transport Group Inventory:

Time (h) = 720.0000

	Atmosphere	Sump	Deposition Surfaces	Recirculating Filter	Overlying Pool
Noble gases (atoms)	0.4782E+18	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Elemental I (atoms)	0.5311E-18	0.0000E+00	0.0000E+00	0.1462E+15	0.0000E+00
Organic I (atoms)	0.1387E+13	0.0000E+00	0.0000E+00	0.3992E+16	0.0000E+00
Aerosols (kg)	0.4610E-42	0.0000E+00	0.0000E+00	0.2111E-08	0.0000E+00

Filter 2--Environment to CR Transport Group Inventory:

Time (h) = 720.0000

	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.5389E+22
Organic I (atoms)	0.1374E+25
Aerosols (kg)	0.5732E-01

Unfiltered--Environment to CR Transport Group Inventory:

Time (h) = 720.0000

	Pathway Filter
Noble gases (atoms)	0.0000E+00
Elemental I (atoms)	0.0000E+00
Organic I (atoms)	0.0000E+00
Aerosols (kg)	0.0000E+00

Exhaust from CR to Environment Transport Group Inventory: 720.00 0.6173E+02 0.4158E+01 0.5810E+02 0.1057E+03
0.1408E+02 0.3618E+02

```
Time (h) = 720.0000
                      Pathway
                      Filter
Noble gases (atoms)   0.0000E+00
Elemental I (atoms)   0.0000E+00
Organic I (atoms)     0.0000E+00
Aerosols (kg)         0.0000E+00
```

###
###############
                     Cumulative Dose Summary
###
###############

Time (hr)	Control Room Thyroid (rem)	Control Room TEDE (rem)	Exclusion Area Bndry Thyroid (rem)	Exclusion Area Bndry TEDE (rem)	Low Population Zone Thyroid (rem)	Low Population Zone TEDE (rem)
0.03	0.4311E-01	0.1863E-02	0.5819E-02	0.2515E-03	0.3803E-04	0.1476E-05
0.17	0.1507E+01	0.6578E-01	0.2034E+00	0.8881E-02	0.5913E-02	0.2363E-03
0.28	0.4076E+01	0.1793E+00	0.5503E+00	0.2420E-01	0.2120E-01	0.8578E-03
0.50	0.1169E+02	0.5112E+00	0.1578E+01	0.6902E-01	0.8510E-01	0.3501E-02
1.18	0.3502E+02	0.1847E+01	0.4728E+01	0.2494E+00	0.3807E+00	0.2242E-01
1.80	0.5660E+02	0.3583E+01	0.7641E+01	0.4837E+00	0.6862E+00	0.6483E-01
2.00	0.6173E+02	0.4158E+01	0.8334E+01	0.5613E+00	0.7816E+00	0.8533E-01
8.00	0.6173E+02	0.4158E+01	0.1379E+02	0.3845E+01	0.1727E+01	0.1253E+01
24.00	0.6173E+02	0.4158E+01	0.1871E+02	0.1641E+02	0.4086E+01	0.7122E+01
48.00	0.6173E+02	0.4158E+01	0.2254E+02	0.2485E+02	0.5175E+01	0.1022E+02
72.00	0.6173E+02	0.4158E+01	0.2553E+02	0.3164E+02	0.5966E+01	0.1252E+02
96.00	0.6173E+02	0.4158E+01	0.2844E+02	0.3824E+02	0.6734E+01	0.1476E+02
120.00	0.6173E+02	0.4158E+01	0.2962E+02	0.4092E+02	0.7043E+01	0.1566E+02
240.00	0.6173E+02	0.4158E+01	0.3545E+02	0.5421E+02	0.8486E+01	0.1987E+02

###
###############
                        I-131 Summary
###
###############

Time (hr)	Annulus I-131 (Curies)	Sprayed Region I-131 (Curies)	Unsprayed Region I-131 (Curies)
0.03	0.7246E+00	0.2745E+06	0.1656E+04
0.17	0.2261E+02	0.1450E+07	0.4953E+05
0.28	0.5681E+02	0.2081E+07	0.2484E+06
0.50	0.1810E+03	0.3152E+07	0.5393E+06
1.18	0.5271E+03	0.2298E+07	0.4975E+06
1.80	0.8146E+03	0.2317E+07	0.4953E+06
2.00	0.8719E+03	0.9242E+06	0.4265E+06
8.00	0.6441E+03	0.5008E+05	0.1107E+05
24.00	0.2279E+03	0.4966E+05	0.1089E+05
48.00	0.7459E+02	0.4953E+05	0.1087E+05
72.00	0.5965E+02	0.4941E+05	0.1084E+05
96.00	0.5808E+02	0.4928E+05	0.1081E+05
120.00	0.5779E+02	0.4916E+05	0.1078E+05
240.00	0.5706E+02	0.4855E+05	0.1065E+05
720.00	0.5428E+02	0.4618E+05	0.1013E+05

Time (hr)	Environment I-131 (Curies)	Control Room I-131 (Curies)
0.03	0.8051E-01	0.2707E-05
0.17	0.2734E+01	0.8104E-04
0.28	0.1410E+01	0.1944E-03
0.50	0.1422E+02	0.3749E-03
1.18	0.1072E+02	0.4505E-03
1.80	0.3193E+01	0.4989E-03
2.00	0.9332E+01	0.4265E-03
8.00	0.1014E+02	0.1473E-03
24.00	0.1210E+02	0.1568E-03
48.00	0.2764E+02	0.5726E-04
72.00	0.2537E+02	0.5330E-04
96.00	0.2509E+02	0.5280E-04
120.00	0.2501E+02	0.3008E-04
240.00	0.2470E+02	0.2970E-04
720.00	0.2349E+02	0.2825E-04

1.7 Problem Report Sheet

RADTRAD PROBLEM REPORT

Return to: Sandia National Laboratories
             PO Box 5800
             Accident Analysis and Consequence Assessment Department
             Albuquerque, NM 87185-0748
             fax (505) 844-3321

Name _____   Date _____

Computer _____   Location _____

Problem Summary _____

****

Problem Classification:

Manual Error   _____   Manual Unclear   _____
Desirable New Feature   _____   Input Error   _____
Calculational Error   _____   Unexplained Termination_____
Small Quantitative Error _____   Large Quantitative Error_____

****

Problem Description:

_____
_____
_____
_____
_____
_____
_____
_____

1.8   References

[Al86]   D.J. Alpert, D.I. Chanin, and L.T. Ritchie, "Relative Importance of Individual Elements to Reactor Accident Consequences Assuming Equal Release Fractions," NUREG/CR-4467, SAND-85-2575, Sandia National Laboratories, Albuquerque, NM, 1986.

[Bi95]   N.E. Bixler, "Simple Model of Pipe Decontamination for RADTRAD," Internal Sandia National Laboratories memorandum to D. Monroe, August 29, 1995.

[Br91]   J.E. Brockmann, "Sampling and Transport of Aerosols" in *Aerosol Measurement: Principles, Techniques, and Applications,* K.Wilke and P.A. Baron, eds., Van Nostrand Reinhold, New York, NY, 1991.

[Ch90]   D.I. Chanin, J.L. Sprung, L.T. Ritchie, and H-N Jow, "Melcor Accident Consequence Code System (MACCS) User's Guide," NUREG/CR-4691, Vol. 1, Sandia National Laboratories, Albuquerque, NM, 1990.

[Cl91]   J.E. Cline, "MSIV Leakage Iodine Transport Analysis," NRC-03-87-029, Nuclear Regulatory Commission, Washington, DC, 1991.

[Di62]   J.J. DiNunno, R.E. Baker, F.D. Anderson, and R.L. Waterfield, "Calculation of Distance Factors for Power and Test Reactor Sites," TID-14844, U.S. Atomic Energy Commission, Washington, DC, 1962.

[Fa84]   Fauske & Associates, Inc., "FAI Aerosol Correlation, An Industry Degraded Core Rulemaking (IDCOR) Program Report," Bethesda, MD, 1984.

Federal Guidance Report No. 11, "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion," EPA 520/1-88-020, U.S. Environmental Protection Agency, Washington, DC, 1988.

Federal Guidance Report No. 12, "External Exposure to Radionuclides in Air, Water and Soil," EPA 420-r-93-081 U.S. Environmental Protection Agency, Washington, DC, 1993.

[Po92]   D.A. Powers and J.L. Sprung, "A Simplified Model of Aerosol Scrubbing by a Water Pool Overlying Core Debris Interacting with Concrete," NUREG/CR-5901, SAND92-1422, Sandia National Laboratories, Albuquerque, NM, 1992.

[Po93]   D.A. Powers, and S.B. Burson, "A Simplified Model of Aerosol Removal by Containment Sprays," NUREG/CR-5966, SAND92-2689, Sandia National Laboratories, Albuquerque, NM, 1993.

[Po95] D. A. Powers, K. E. Washington, S. B. Burson, and J. L. Sprung, "A Simplified Model of Aerosol Removal by Natural Process in Reactor Containments," NUREG/CR-6189, SAND94-0407, Sandia National Laboratories, Albuquerque, NM, 1995.

[Ra95] J. V. Ramsdell, C.A. Simonen, and S.B. Smyth, "Atmospheric Relative Concentrations in Building Wakes," NUREG/CR-6331, PNL-10521, Pacific Northwest National Laboratory, Richland, WA, 1995.

[So95] L.Soffer, S.B.Burson, C.M.Ferrell, R.Y.Lee, and J.N.Ridgely, "Accident Source Terms for Light-Water Nuclear Power Plants," NUREG-1465, Nuclear Regulatory Commission, Washington, DC, 1995.

USNRC [74] "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Boiling Water Reactors," Regulatory Guide 1.3, Revision 2, Nuclear Regulatory Commission, Washington, DC, 1974.

USNRC [74] "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Pressurized Water Reactors," Regulatory Guide 1.4, Revision 2, Nuclear Regulatory Commission, Washington, DC, 1974.

WASH-1400 [75] "Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," WASH-1400, NUREG 75/014, Nuclear Regulatory Commission, Washington, DC, 1975.
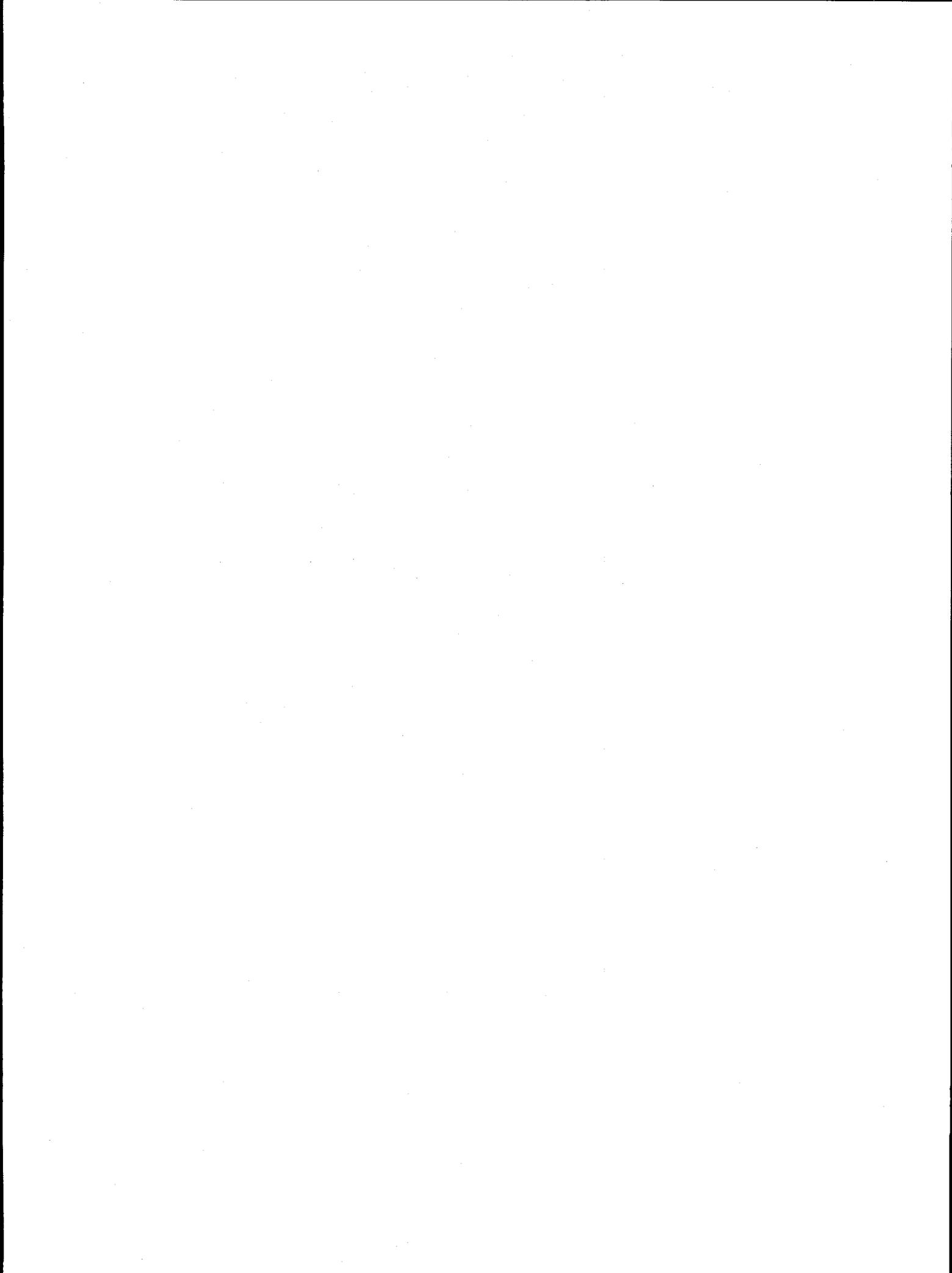
2 Technical Bases for RADTRAD

The radiological consequences of an accident in a nuclear reactor depend upon the quantity of the radioactive material that escapes to the environment or enters the control room. RADTRAD is designed to calculate doses at offsite locations, such as the low population zone, and in the control room. The code has two default source terms to describe fission product release to the containment: those from TID-14844 [Di62] and those from NUREG-1465 [So1995] are discussed in Section 1.4.3. As the material is transported through the containment and other buildings, credit is given for several natural and engineered removal mechanisms. Containment sprays remove aerosols, elemental iodine, and organic iodine. The flow between buildings or rooms may be through HEPA filters or a suppression pool. Leakage to the environment may occur. Aerosols can deposit on surfaces within rooms and also in connecting paths. Models are included for these different removal mechanisms. Alternatively, the user may elect to input time-dependent values for the removal coefficient. In Sections 2.1 and 2.2 the technical bases for the RADTRAD model of these phenomena are discussed. After transporting the nuclides to different locations, RADTRAD calculates the dose at user-specified locations. Section 2.3 discusses the technical basis for this model.

The numerical solutions used by the code to solve these equations are discussed in Section 2.4. The code uses a Laplace transform method to solve the transport problem as discussed in Section 2.4.2. The technical basis for the radioactive decay and daughter in-growth model in the RADTRAD calculation is discussed in Section 2.4.3.

2.1 Transport and Removal

The basic equation for radionuclide transport and removal is the same for all compartments. However, depending on the removal mechanisms available within a compartment or between two compartments, some of the coefficients in the equation may be zero. This section describes the general equation used for the in-plant transport and removal of fission products.

2.1.1 Governing Equations

The governing equation for the number of atoms of nuclide n, in compartment i, during time step m is provided with all source and sink terms explicitly shown for clarity. The time step m refers to the scenario-dependent and supplemental time steps. Supplemental time steps are defined by the user in the **Calculate Results** screen (screen number 3000). Scenario-dependent time steps end when an input changes state (e.g., when sprays are turned on).

$$\frac{d}{dt} N^m_{n,i} = \sum_{v=1}^{n-1} \beta_{n,v} N^m_{v,i} \lambda_v + S^m_{n,i}$$

$$-\left[\sum_{\substack{j=1 \\ j \neq i}}^{L} \left[F^m_{i,j(conv)} + \frac{Q^m_{i,j(s)}}{Vol_i} + \frac{Q^m_{i,j(p)}}{Vol_i} \right] + \lambda_n + \lambda^m_{spr,n}(t) + \lambda^m_{dep,n}(t) + \frac{\eta^m_{n:i,j}}{100} F^m_{i,j(forced)} \right] N^m_{n,i}$$

$$+ \sum_{\substack{j=1 \\ j \neq i}}^{L} \left[\left(1 - \frac{\eta^m_{n:i,j}}{100} \right) F^m_{i,j(forced)} + F^m_{i,j(conv)} + \frac{Q^m_{i,j(s)}}{Vol_j DF^m_{n(s)}} + \frac{Q^m_{i,j(p)}}{Vol_j DF^m_{n(p)}} \right] N^m_{n,j} \qquad (1)$$

$$\lambda_n = \ln(2) / T_n^{1/2} \qquad (2)$$

where:

$N^m_{n,i} =$ number of atoms of nuclide n in compartment i during time step m

$\beta_{n,v} =$ fraction of nuclide v that decays to nuclide n (dimensionless)

$\lambda_n =$ radiological decay constant for nuclide n (s^{-1})

$T_n^{1/2} =$ half-life of nuclide n (s)

$F^m_{i,j(conv)} =$ volume-normalized convective (leakage) air flow rate from compartment j to i (s^{-1})

$F^m_{i,j(forced)} =$ volume-normalized forced air flow rate from compartment j to i (s^{-1})

$L =$ number of compartments defined in the plant model

$Q^m_{i,j(s)} =$ volumetric flow rate from compartment j to i through a suppression pool (m^3/s)

$Q^m_{i,j(p)} =$ volumetric flow rate from compartment j to i through a pipe (m^3/s)

$Vol_k =$ volume of compartment k (m^3)

$DF^m_{n(s)} =$ suppression pool decontamination factor for nuclide n during time step m (dimensionless)

$DF^m_{n(p)} =$ piping decontamination factor for nuclide n during time step m (unitless)

$\lambda^m_{spr,n}(t) =$ time-dependent spray removal coefficient for nuclide n (s^{-1})

$\lambda^m_{dep,n}(t) =$ time-dependent natural deposition removal rate coefficient for nuclide n (s^{-1})

$S_{n,i}^{m} =$ source injection rate of nuclide n to compartment i during time step m (atoms/s)

$\eta_{n:i,j}^{m} =$ filter efficiency associated with nuclide n and the pathway from j to i (%)

The first line of the equation relates the change in nuclide inventory within volume i due to the increase from nuclide decay λ_n plus the increase due to the source injection, typically from the nuclides being released during the accident from the reactor coolant system to the containment. The second line details the various removal mechanisms that can be active in volume i plus the removal due to decay of nuclide n. These range from atoms exiting the volume due to leakage and flow through pathways, to atoms being deposited on the walls or floor of the volume. The third line details the pathways that can be used to add nuclide n to the volume, typically from transport from other volumes.

Equation 1 is solved by RADTRAD using the assumption that all nuclides can be grouped according to their chemical and transport similarities. Thus four transport groups were used: noble gases, elemental iodine, organic iodine, and aerosols. These four groups transport and react with their surroundings differently, but all components of any one group act the same. This implies that all xenon and krypton isotopes will transport identically and that cesium, barium, and all other aerosol isotopes will transport identically. The user specifies the fractions for the released iodine and thus partitions the iodine within the latter three groups. The removal mechanisms are discussed in Section 2.2, the mathematical solution to the transport problems in Section 2.4, and the logic flow and program details in Section 4.

2.2 Removal Phenomena

Sprays, natural deposition, leakage, natural and forced convection, filters, and suppression pools are treated as mechanisms for removing radioactive material from the compartment atmospheres. In addition, during a severe accident, overlying pools can reduce the ex-vessel release into the containment atmosphere. The material that is removed from the compartment atmosphere by these mechanisms will not reappear in that compartment with the few exceptions that will be noted in the following subsections. The driving routine to determine the individual removal phenomena was implemented in COEFFS.

It is common practice to relate some removal mechanisms to particular loss terms. For example, filters are discussed in terms of efficiencies, and natural deposition in terms of removal coefficients. These are related to each other as well as to decontamination factor (DF). The decontamination factor is defined as the ratio of the total aerosol material subjected to a removal process to the total aerosol material that remains airborne. The relationship between decontamination factor and removal coefficient, λ, is:

$$\frac{dDF}{dt} = \lambda DF \qquad (3)$$

The average decontamination factor is related to the mass fraction, m_f, remaining in the volume as:

$$m_f = \frac{M(t)}{M(0)} = \frac{1}{DF} = \exp(-\lambda \ t) \tag{4}$$

The decontamination factor is also related to the removal efficiency, η, as:

$$DF = \frac{1}{1 - \eta} \tag{5}$$

In the first three subsections, sprays, natural deposition, and overlying pools will be discussed. These are all phenomena that occur within a volume. The following three subsections then discuss the mass removal phenomena that occur between volumes, i.e., leakage, suppression pools and deposition in piping. The last subsection discusses filters as they occur both in pathways between volumes, for example a control room intake filter, and within a volume, such as a control room recirculating filter.

2.2.1 Sprays

Sprays may remove aerosols and iodine. It is assumed that the noble gases are not affected by sprays. The code currently provides the user with a choice of an aerosol removal model or a user-specified aerosol removal coefficient table. Only the user-provided removal coefficient table option is available for elemental and organic iodine removal by sprays. The use of sprays will result in a user-provided sump filling with the spray water. The primary routine for spray phenomena is SPRY.

2.2.1.1 Powers Model for Aerosol Removal

The user may specify the Powers model [Po93] or a table for the aerosol removal coefficient as a function of time. The extent to which sprays will decontaminate an aerosol-laden atmosphere depends on the number of spray droplets falling through the atmosphere and the distance they fall. The water flux into the containment atmosphere is time dependent and they fall distance is dependent upon the containment design. In the Powers document, a mechanistic model of aerosol removal by sprays is derived based upon how a single falling droplet would scavenge particles. Powers suggested that many of the properties and phenomena affecting the process are not accurately predictable. To account for these uncertainties, a large number of calculations were performed with the mechanistic model (with specific values for the height and water flux) and varying the uncertain parameters. Typical uncertain parameters were the containment pressure, the aerosol particle size, the water droplet distribution, the dynamic shape factors, and the properties of the water. In all, 20 parameters that were related to the phenomena were varied. An uncertainty analysis was performed using a Monte Carlo method to sample all the calculations. The results were used to construct simplified expressions for spray removal coefficients. The model input parameters are the spray water flux, W (m^3 H_2O / m^2 s) and the fall height of the spray droplets H (m). Since the model was developed from an uncertainty study, the

user specifies a percentile. The "best estimate" value is associated with the 50th percentile, or median values; the lower bound is associated with the 10th percentile; and the reasonable upper bound, or largest decontamination factor, with the 90th percentile. The model was developed using values of 10, 100, and 2500 cm^3 H$_2$O/ cm^2 s for the spray water flux, W, and fall heights of 500, 853, 1000, 1584, 2000, 3000, 4000, and 5000 cm. The model should not be used for spray water fluxes and fall heights outside of these ranges. The aerosol removal coefficient is dependent on the fraction of the aerosol suspended in the atmosphere, m_f, which is defined as the aerosol mass in the atmosphere of a compartment at a given time, t, divided by the total aerosol mass released into the compartment atmosphere until this time. The model includes the effect of the unsprayed portions of the containment by incorporating the assumption that the circulation in the compartment is rapid compared with the removal rate. The equation that specifies the aerosol removal coefficient, λ, at any time is:

$$\lambda(s^{-1}) = \frac{1}{3600(1+\alpha)}\left(\left(a+b\log^{10}W\right)\left\{1 - \left[\frac{m_f(t)}{0.9}\right]^c\right\} + \left(\frac{m_f(t)}{0.9}\right)^c\right)$$
$$\exp\left(A + B\ln W + C H + D W^2 H\right.$$
$$\left. + E WH^2 + F W + G W^2 H^2\right)$$

$$(6)$$

The constants **A, B, C, D, E, F, G, a, b,** and **c** are defined in Table 2.2.1.1-1. The parameter α is the ratio of the compartment volume not exposed to sprays to the compartment volume exposed to sprays (unsprayed volume/sprayed volume). If the assumption that the circulation is rapid compared with the removal rate is not valid, then the user can split the compartment into two separate compartments and model the flow from the unsprayed portions to the sprayed portions as a convective flow. In this case α would be zero for the compartment containing the sprays.

This expression was originally developed for a puff release of aerosols into a system. In those cases where there is a continuing release, the size distribution will continually be renewed by the injected particulate. The model has been extended for this case by setting coefficients **A** through **G** to zero. This makes the model assume that the size distribution has not changed in time and that most of the material suspended is fresh material provided by the source. The aerosols removed by the sprays are placed in the sump.

Table 2.2.1.1-1. Values for constants used in equation 2 [Chapter 7, Po93]

Constant	Value		
	10th **Percentile**	50th **Percentile**	90th **Percentile**
A	5.5750	6.83707	7.10927
B	0.94362	1.0074	0.92549
C	0.0	-2.4045×10^{-5}	0.0
D	-6.9821×10^{-3}	-4.1731×10^{-3}	-8.0868×10^{-4}
E	-7.327×10^{-7}	9.006×10^{-8}	0.0
F	0.0	-1.2478	0.0
G	3.555×10^{-6}	0.0	0.0
a	0.1108	0.1815	0.3751
b	-0.00201	-0.01153	0.00648
c	0.8945	0.5843	0.2786

2.2.1.2 Elemental Iodine Removal

The user may specify a table with the spray removal coefficient for elemental iodine as a function of time. Along with the aerosols removed by the sprays, the removed iodine is located in the sump.

2.2.1.3 Organic Iodine Removal

The user may specify a table with the spray removal coefficient for organic iodine removal as a function of time. Organic iodine is not usually removed by sprays, but the option is available.

2.2.2 Natural Deposition

Natural deposition includes many phenomena (e.g., gravitational settling, thermophoresis, diffusiophoresis). This removal mechanism is considered valid only for aerosols and perhaps elemental iodine; organic iodine and noble gases are nonreactive and therefore are not likely to be affected by these mechanisms. The user may choose a model for aerosol natural deposition or may specify time-dependent removal coefficients. A removal coefficient must be specified for the elemental iodine. The primary routine for natural deposition phenomena is XNTDEP. The removed iodine adheres to the surfaces of the volume.

2.2.2.1 Aerosols

The user may specify a model or provide a table for the natural deposition removal coefficient as a function of time. There are two choices for models of natural deposition, one based upon Henry's analysis [Fa84] and one based upon Powers' analysis [Po95].

2.2.2.1.1 Henry's Correlation. The correlation developed by Henry [Fa84] is based upon observation of experiments concerned with aerosol decontamination. The form of the equation is based upon the consideration that sedimentation was the dominant phenomenon observed, and the coefficients were determined from experimental data from liquid metal reactor tests. The coefficients that best follow the data are

$$\lambda = C_1 \left(\frac{h_{ref}}{h} \right) \left(\frac{\rho_P}{\rho_{P_{ref}}} \right) (\rho_A)^K \tag{7}$$

where:

$$C_1 = 0.0220; \quad k = 0.60 \quad \text{for } \rho_A \geq 6.0 \times 10^{-5} \text{ kg} / \text{m}^3 \tag{8}$$

and:

$$C_1 = 0.0016; \quad k = 0.33 \quad \text{for } \rho_A < 6.0 \times 10^{-5} \text{ kg} / \text{m}^3 \tag{9}$$

where:

ρ_A = the aerosol mass in the volume

h_{ref} = 5.0 m, as determined from the ABCOVE test AB5

$\rho_{P_{ref}}$ = theoretical sodium oxide particle density of 2270 kg/m^3, as determined from the ABCOVE test AB5

ρ_p = user-provided particle density (kg/m^3)

h = user-provided fall height (m)

Henry's correlation input can be modified to account for the influence of aerosol shape and moisture by:

$$\rho_P = \alpha \rho_T + (1 - \alpha) \rho_w \tag{10}$$

where:

α = ratio of the effective aerosol particle density to theoretical density

ρ_T = theoretical density (kg/m^3)

ρ_w = density of water (kg/m^3)

In many cases the aerosol has only 20% of its theoretical density, so that in a high steam environment its effective density would be closer to that of water. The correlation was implemented in the routine XNTDEP.

2.2.2.1.2 Powers Model. The model developed by Powers et al.   is a continuation of the work of Otter and Vaughn [Ot 86], which followed the work of Epstein and Ellison [Ep 87]. In these models the observation of a self-preserving aerosol size distribution is a key component in predicting aerosol behavior. Powers added the effects due to turbulence and to the multiple aerosol releases specified in NUREG-1465. The modified model was then compared with a series of CONTAIN [WA 91] cases to verify the aging and aerosol size distributions due to the multiple sources. To account for the uncertainties, a large number of calculations were performed with the modified mechanistic model, with specific values for the type of reactor containment, reactor power, and the source term release phase, while varying the values of the uncertain parameters. Typical uncertain parameters were the containment pressure during the various release phases, the floor and wall surface areas, the zirconium inventory, the ratio of containment volume to thermal power, and the properties of the concrete. In all, over 20 parameters that were related to the phenomena were varied. The final, highly simplified model for aerosol decontamination is described by:

$$\frac{d\,DF_i(t)}{dt} = \lambda_{dep,I}\left(P_{th},t\right)DF_i(t) \qquad (11)$$

where:

$DF_i(t) =$ 	decontamination factor for the ith class of radioactive aerosol at time t where I indicates when the material was released into the containment: during the gap, in-vessel, ex-vessel, or late in-vessel phases of a severe reactor accident

$\lambda_{dep,I}(P_{th},t) =$ 	decontamination coefficient at time t and power P_{th} for phase I, and

$P_{th} =$ 	thermal power of the reactor in question.

The decontamination coefficient, λ, was solved over the various release time intervals and for the different types of reactors and various operating power levels using a Monte Carlo uncertainty analysis. The results of these analyses are detailed in Tables 2.2.2.1-1 through 5 and are given in terms of percentile decontamination factors, $\lambda_{dep}(N\%,P_{th})$. Since the model was developed from an uncertainty study, the user specifies a percentile, $N\%$. The "best estimate" value is associated with the 50th percentile, or median values; the lower bound is associated with the 10th percentile; and the reasonable upper bound, or largest decontamination factor, with the 90th percentile. Note that the tables were developed for both design basis and severe accident scenarios for generic PWRs and BWRs. The controlling logic was implemented in routine AEROSOL. This routine determines the current decontamination coefficient, λ_{net}, from the sum of the coefficients for each phase weighted by the iodine release rate, $S_{I2,I}$, for phase I. Thus,

$$\lambda_{net} = \frac{\ln\left\{[DF(t+\Delta t)/DF(t)]\right\}}{\Delta t} \qquad (12)$$

where

$$DF(t) = \frac{\sum_{I=1}^{4} S_{12,I}}{\sum_{I=1}^{4} S_{12,I} / DF_I} \qquad (13)$$

$$DF_I = \prod_{I=1}^{4} \exp\left[\lambda_{dep,I}(N\%, P_{th})\, t\right] \qquad (14)$$

To compare with the original Powers document, the decontamination coefficient should be weighted by each chemical group release rate. RADTRAD does not maintain the necessary weighting factors, hence a single chemical release rate was used for the weighting coefficients. For both the severe accident and the design basis accident calculations, iodine was chosen because it releases in all four phases and is the most radiologically important. If a case is developed where the most important aerosol has a release rate significantly different than the iodine release rate, then some modification to the logic would be necessary.

Table 2.2.2.1-5 provides the decontamination coefficients for a design basis accident in an advanced PWR design. These values are based upon a Powers document [Po 97b] in which it was found that the CONTAIN-related calculation results were correlated with values in the table. These correlations do not vary with reactor thermal power; hence an approximation is used when the user selects a PWR design with a different power level. The approximation used assumes that the significant difference between the PWR and the advanced pressurized water reactor (APWR) design, in terms of natural deposition, is that the wall cooling enhances the phoretic deposition. Therefore the difference in decontamination coefficient at 1800 MWt represents this phoretic deposition and is then scaled by the power ratio. The final approximation used is:

$$\lambda_{net}(AP\_Power) = \lambda_{net}(PWR\_P_{th}) + \left[\lambda_{net}(PWR\_1800) - \lambda_{net}(PWR\_1800)\right]\frac{P_{th}}{1800} \qquad (15)$$

where

$\lambda_{dep}(PWR\_1800)$ = decontamination coefficient from the PWR-1800 calculation

$\lambda_{dep}(PWR\_P_{th})$ = decontamination coefficient from the PWR design basis accident calculation for the power level indicated.

2.2.2.2 Elemental Iodine Removal

The user may specify a table for the natural deposition removal coefficient for elemental iodine as a function of time.

Table 2.2.2.1-1 Correlation of PWR effective natural deposition decontamination coefficients with reactor thermal power P(MWt) for design basis accidents [Table 36, Po95]

Release Phase	Time Interval (s)	Correlation[1] (hr^{-1})
gap	0-1800 (0-0.5 hr)	$\lambda_{dep}(90) = 0.0365 + 3.580 \times 10^{-6} P(MWt)$ $\lambda_{dep}(50) = 0.0268 + 3.475 \times 10^{-6} P(MWt)$ $\lambda_{dep}(10) = 0.0182 + 3.260 \times 10^{-6} P(MWt)$
gap	1800-6480 (0.5-1.8 hr)	$\lambda_{dep}(90) = 0.1036 \, [1 - \exp(-2.239 \, P(MWt)/1000)]$ $\lambda_{dep}(50) = 0.0820 \, [1 - \exp(-1.159 \, P(MWt)/1000)]$ $\lambda_{dep}(10) = 0.0645 \, [1 - \exp(-0.938 \, P(MWt)/1000)]$
early in-vessel	1800-6480 (0.5-1.8 hr)	$\lambda_{dep}(90) = 0.0522 \, [1 - \exp(-2.458 \, P(MWt)/1000)]$ $\lambda_{dep}(50) = 0.0417 \, [1 - \exp(-1.258 \, P(MWt)/1000)]$ $\lambda_{dep}(10) = 0.0326 \, [1 - \exp(-0.910 \, P(MWt)/1000)]$
gap + early in-vessel	6480-13,680 (1.8-3.8 hr)	$\lambda_{dep}(90) = 0.421 \, [1 - \exp(-2.530 \, P(MWt)/1000)]$ $\lambda_{dep}(50) = 0.196 \, [1 - \exp(-1.040 \, P(MWt)/1000)]$ $\lambda_{dep}(10) = 0.094 \, [I - \exp(-0.869 \, P(MWt)/1000)]$
gap + early in-vessel	13,680-49,680 (3.8-13.8 hr)	$\lambda_{dep}(90) = 0.1920 - 1.35 \times 10^{-6} P(MWt)$ $\lambda_{dep}(50) = 0.1382 + 6.85 \times 10^{-6} P(MWt)$ $\lambda_{dep}(10) = 0.0811 + 10.15 \times 10^{-6} P(MWt)$
gap + early in-vessel	49,680-80,000 (13.8-22.22 hr)	$\lambda_{dep}(90) = 0.1010$ $\lambda_{dep}(50) = 0.0912$ $\lambda_{dep}(10) = 0.0860 \, [1 - \exp(-2.384 \, P(MWt)/1000)]$

[1] $\lambda_{dep}(50)$ is the 50 percentile or median effective decontamination coefficient. $\lambda_{dep}(90)$ and $\lambda_{dep}(10)$ are the 90th and 10th percentile values, respectively.

Table 2.2.2.1-2 Correlation of PWR effective natural deposition decontamination coefficients with reactor thermal power for severe accidents [Table 26, Po95]

Release Phase	Time Interval (s)	Correlations[1] (hr^{-1})
gap	0-1800 (0 -0.5 hr)	$\lambda_{dep}(90) = 0.0349 + 3.755 \times 10^{-6}\,P(MWt)$ $\lambda_{dep}(50) = 0.0256 + 3.90 \times 10^{-6}\,P(MWt)$ $\lambda_{dep}(10) = 0.0167 + 3.25 \times 10^{-6}\,P(MWt)$
gap	1800-6-4.80 (0.5 1.8 hr)	$\lambda_{dep}(90) = 0.0808 + 5.955 \times 10^{-6}\,P(MWt)$ $\lambda_{dep}(50) = 0.0174 + 8.39 \times 10^{-6}\,P(MWt)$ $\lambda_{dep}(10) = 0.0322 + 7.16 \times 10^{-6}\,P(MWt)$
early in-vessel	1800-6480 (0.5-1.8 hr)	$\lambda_{dep}(90) = 0.0505 + 0.94 \times 10^{-6}\,P(MWt)$ $\lambda_{dep}(50) = 0.0257 + 3.87 \times 10^{-6}\,P(MWt)$ $\lambda_{dep}(10) = 0.0166 + 3.49 \times 10^{-6}\,P(MWt)$
gap + early in-vessel	6480-13,680 (1.8-3.8 hr)	$\lambda_{dep}(90) = 0.1146 + 371.9/P(MWt)$ $\lambda_{dep}(50) = 0.0948 + 141.2/P(MWt)$ $\lambda_{dep}(10) = 0.0472 + 62.0/P(MWt)$
ex-vessel + late in-vessel	6480-13,680 (1.8-3.8 hr)	$\lambda_{dep}(90) = 0.0754 + 184.9/P(MWt)$ $\lambda_{dep}(50) = 0.0551 + 84.65/P(MWt)$ $\lambda_{dep}(10) = 0.0272 + 42.0/P(MWt)$
gap + early in-vessel + ex-vessel	13,680-42,480 (3.8-11.8 hr)	$\lambda_{dep}(90) = 0.378 + 161.6/P(MWt)$ $\lambda_{dep}(50) = 0.269 + 141.2/P(MWt)$ $\lambda_{dep}(10) = 0.068 + 81.8/P(MWt)$
late in-vessel	13,680-42,480 (3.8-11.8 hr)	$\lambda_{dep}(90) = 0.0829 - 3.40 \times 10^{-6}\,P(MWt)$ $\lambda_{dep}(50) = 0.0547 - 0.62 \times 10^{-6}\,P(MWt)$ $\lambda_{dep}(10) = 0.0222 + 6.44 \times 10^{-6}\,P(MWt)$
gap + early in-vessel + ex-vessel + late in-vessel	42,480-80,000 (11.8-22.22 hr)	$\lambda_{dep}(90) = 0.210 + 50.6/P(MWt)$ $\lambda_{dep}(50) = 0.144$ $\lambda_{dep}(10) = 0.0915\,[1 - \exp\,(-2.216\,P(MWt)/1000)]$
gap early in-vessel + ex-vessel + late in-vessel	80,000-100,000 (22.22-27.78 hr)	$\lambda_{dep}(90) = 0.0933 + 12.0/P(MWt)$ $\lambda_{dep}(50) = 0.0838$ $\lambda_{dep}(10) = 0\,0377$
gap early in-vessel + ex-vessel + late in-vessel	100,000-120,000 (22.78-33.33 hr)	$\lambda_{dep}(90) = 0.0717 + 10.8/P(MWt)$ $\lambda_{dep}(50) = 0.0669$ $\lambda_{dep}(10) = 0.0277$

[1] $\lambda_{dep}(50)$ is the median of the uncertainty distribution. The 90th and 10th percentile values are $\lambda_{dep}(90)$ and $\lambda_{dep}(10)$, respectively.

Table 2.2.2.1-3 Correlations of BWR effective natural deposition decontamination coefficients with reactor thermal power for design basis accidents [Table A-19, Po97a]

Release Phase	Time Interval (s)	Correlations[1] (hr^{-1})
gap	0-1800 (0-0.5 hr)	$\lambda_{dep}(90) = 2.903\ [exp(-1060/P(MWt)]$ $\lambda_{dep}(50) = 2.252\ [exp(-1977/P(MWt)]$ $\lambda_{dep}(10) = 1.285\ [exp(-2119/P(MWt)]$
gap	1800-7200 (0.5-2.0 hr)	$\lambda_{dep}(90) = 1.809\ [exp(-777/P(MWt)]$ $\lambda_{dep}(50) = 1.722\ [exp(-1777/P(MWt)]$ $\lambda_{dep}(10) = 1.161\ [exp(-2274/P(MWt)]$
early in-vessel	1800-7200 (0.5-2.0 hr)	$\lambda_{dep}(90) = 0.746\ [exp(-626/P(MWt)]$ $\lambda_{dep}(50) = 0.752\ [exp(-1565/P(MWt)]$ $\lambda_{dep}(10) = 0.520\ [exp(-2173/P(MWt)]$
gap + early in-vessel	7200-18,000 (2.0-5.0 hr)	$\lambda_{dep}(90) = 1.959\ [exp(-548/P(MWt)]$ $\lambda_{dep}(50) = 1.811\ [exp(-1107/P(MWt)]$ $\lambda_{dep}(10) = 1.551\ [exp(-1507/P(MWt)]$
gap + early in-vessel	18,000-30,000 (5.0-8.33 hr)	$\lambda_{dep}(90) = 1.533\ [exp(-573/P(MWt)]$ $\lambda_{dep}(50) = 1.317\ [exp(-1225/P(MWt)]$ $\lambda_{dep}(10) = 0.836\ [exp(-1051/P(MWt)]$
gap + early in-vessel	30,000-43,200 (8.33-12.0 hr)	$\lambda_{dep}(90) = 1.524\ [exp(-647/P(MWt)]$ $\lambda_{dep}(50) = 1.339\ [exp(-1474/P(MWt)]$ $\lambda_{dep}(10) = 0.780\ [exp(-1316/P(MWt)]$
gap + early in-vessel	43,200-70,000 (12.0-19.4 hr)	$\lambda_{dep}(90) = 1.564\ [exp(-717/P(MWt)]$ $\lambda_{dep}(50) = 1.373\ [exp(-1634/P(MWt)]$ $\lambda_{dep}(10) = 0.778[exp(-1548/P(MWt)]$
gap + early in-vessel	70,000-86,400 (19.4-24.0 hr)	$\lambda_{dep}(90) = 1.562\ [exp(-719/P(MWt)]$ $\lambda_{dep}(50) = 1.441\ [exp(-1785/P(MWt)]$ $\lambda_{dep}(10) = 0.780\ [exp(-1686/P(MWt)]$

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[1] $\lambda_{dep}(50)$ is the 50 percentile or median effective decontamination coefficient. $\lambda_{dep}(90)$ and $\lambda_{dep}(10)$ are the 90th and 10th percentile values, respectively.

Table 2.2.2.1-4 Correlations of BWR effective natural deposition decontamination coefficients with reactor thermal power, (MWt) for severe accidents [Table A-10, Po97a]

Release Phase	Time Interval (s)	Correlations[1] (hr^{-1})
gap	0-1800 (0.-0.5 hr)	$\lambda_{dep}(90) = 4.074 \, [\exp(-1165/P(MWt))]$ $\lambda_{dep}(50) = 3.517 \, [\exp(-2534/P(MWt))]$ $\lambda_{dep}(10) = 1.919 \, [\exp(-2767/P(MWt))]$
gap	1800-7200 (0.5-2.0 hr)	$\lambda_{dep}(90) = 5.132 \, [\exp(-1557/P(MWt))]$ $\lambda_{dep}(50) = 3.155 \, [\exp(-2407/P(MWt))]$ $\lambda_{dep}(10) = 1.558 \, [\exp(-2646/P(MWt))]$
early in-vessel	1800-7200 (0.5-2.0 hr)	$\lambda_{dep}(90) = 1.446 \, [\exp(-1012/P(MWt))]$ $\lambda_{dep}(50) = 1.202 \, [\exp(-2045/P(MWt))]$ $\lambda_{dep}(10) = 0.724 \, [\exp(-2498/P(MWt))]$
gap + early in-vessel	7200-18,000 (2.0-5.0 hr)	$\lambda_{dep}(90) = 2.224 \, [\exp(-116/P(MWt))]$ $\lambda_{dep}(50) = 1.479 \, [\exp(-500/P(MWt))]$ $\lambda_{dep}(10) = 0.939 \, [\exp(-616/P(MWt))]$
ex-vessel + late in-vessel	7200-18,000 (2.0-5.0 hr)	$\lambda_{dep}(90) = 0.639 \, [\exp(-62/P(MWt))]$ $\lambda_{dep}(50) = 0.525 \, [\exp(-302/P(MWt))]$ $\lambda_{dep}(10) = 0.394 \, [\exp(-429/P(MWt))]$
gap + early in-vessel + ex-vessel	18,000-43,200 (5.0-12.0 hr)	$\lambda_{dep}(90) = 1.037 \, [\exp(-240/P(MWt))]$ $\lambda_{dep}(50) = 0.779 \, [\exp(-252/P(MWt))]$ $\lambda_{dep}(10) = 0.576 \, [\exp(-172/P(MWt))]$
late in-vessel	18,000-43,200 (5.0-12.0 hr)	$\lambda_{dep}(90) = 0.052$ $\lambda_{dep}(50) = 0.00075$ $\lambda_{dep}(10) = 0.000005$
gap + early in-vessel + ex-vessel + late in-vessel	43,200-80,000 (12.0-22.2 hr)	$\lambda_{dep}(90) = 0.704 \, [\exp(-468/P(MWt))]$ $\lambda_{dep}(50) = 0.445 \, [\exp(-630/P(MWt))]$ $\lambda_{dep}(10) = 0.295 \, [\exp(-849/P(MWt))]$
gap + early in-vessel + ex-vessel + late in-vessel	80,000-100,000 (22.2-27.8 hr)	$\lambda_{dep}(90) = 0.700 \, [\exp(-717/P(MWt))]$ $\lambda_{dep}(50) = 0.463 \, [\exp(-1242/P(MWt))]$ $\lambda_{dep}(10) = 0.217 \, [\exp(-894/P(MWt))]$
gap + early in-vessel + ex-vessel + late in-vessel	100,000-120,000 (27.8-33.3 hr)	$\lambda_{dep}(90) = 0.665 \, [\exp(-643/P(MWt))]$ $\lambda_{dep}(50) = 0.473 \, [\exp(-1384/P(MWt))]$ $\lambda_{dep}(10) = 0.196 [\exp(-945/P(MWt))]$

[1] $\lambda_{dep}(50)$ is the 50 percentile or median effective decontamination coefficient.

Table 2.2.2.1-5 Correlations of APWR effective natural deposition decontamination coefficients for design basis accidents [Table 15, Po97b]

Release Phase	Time Interval (s)	Correlations[1] (hr^{-1})
gap	0-1800 (0-0.5 hr)	$\lambda_{dep}(90) = 0.466$ $\lambda_{dep}(50) = 0.233$ $\lambda_{dep}(10) = 0.029$
gap	1800-6480 (0.5-1.8 hr)	$\lambda_{dep}(90) = 0.872$ $\lambda_{dep}(50) = 0.487$ $\lambda_{dep}(10) = 0.160$
early in-vessel	1800-6480 (0.5-1.8 hr)	$\lambda_{dep}(90) = 0.393$ $\lambda_{dep}(50) = 0.240$ $\lambda_{dep}(10) = 0.100$
gap + early in-vessel	6480-13,680 (1.8-3.8 hr)	$\lambda_{dep}(90) = 1.210$ $\lambda_{dep}(50) = 0.980$ $\lambda_{dep}(10) = 0.731$
gap + early in-vessel	13,680-49,680 (3.8-13.8 hr)	$\lambda_{dep}(90) = 0.594$ $\lambda_{dep}(50) = 0.397$ $\lambda_{dep}(10) = 0.245$
gap + early in-vessel	49,680-86,400 (13.8-24.0 hr)	$\lambda_{dep}(90) = 0.598$ $\lambda_{dep}(50) = 0.327$ $\lambda_{dep}(10) = 0.107$

[1] $\lambda_{dep}(50)$ is the 50 percentile or median effective decontamination coefficient. $\lambda_{dep}(90)$ and $\lambda_{dep}(10)$ are the 90th and 10th percentile values, respectively.

2.2.3 Overlying Pools

Overlying pools are modeled as an in-compartment decontamination process similar to that for sprays and natural deposition. Overlying pools only affect the ex-vessel phase of fission product release from a severe accident. A model is available for the removal of fission products during transport through the pool. Alternatively, the user may specify decontamination factors as function of time. Noble gases are assumed not to interact with the pool and are transmitted without any depletion.

2.2.3. Powers Model for Aerosol Removal

The Powers model [Po92] was developed by performing an uncertainty study using a model for aerosol scrubbing from bubbles rising through water (the POOL model from the VANESA code, Chapter 7 [Po86]). The uncertainty analysis was performed using the Monte Carlo method to sample 15 parameters related to phenomena connected with concrete erosion, the aerosols in the pool, and pool-bubble dynamics. The results of the uncertainty study were used to construct simple correlations relating the pool depth, subcooling, and uncertainty to the decontamination factor. Since the model was developed from an uncertainty study, the user specifies a percentile. The "best estimate" value is associated with the 50th percentile, or median values; the lower bound is associated with the 10th percentile; and the reasonable upper bound, or largest decontamination factor, with the 90th percentile. The equations were developed using pool depths of 30, 50, 100, 200, 300, and 500 cm and subcooling levels of 0, 2, 5, 10, 20, 30, 50, and 70 K. For pools with a depth of less than 30 cm, the decontamination factor is taken as that for a pool of 30-cm depth. For pools with a depth greater than 500 cm, the decontamination factor is taken as that for a pool of 500-cm depth.

For a saturated pool, the general form of the decontamination factor equation is

$$\ln(DF) \; = \; a \; + \; b\,H^{1/2} + c\,H^{3/2} + d\,H^3 \tag{16}$$

where H is the pool depth (cm).

The constants a, b, c, and d are defined in Table 2.2.3.1-1 for the three different percentiles.

Table 2.2.3.1-1. Values for the constant used in equation 16 [Chapter 5, Po92]

Constant	Values		
	10th Percentile	50th Percentile	90th Percentile
a	-0.1832417	-0.195036	0.114994
b	0.0879653	0.17976	0.29587
c	8.192503×10^{-5}	0.0	0.0
d	$-1.2281546 \times 10^{-9}$	4.68319×10^{-9}	1.087539×10^{-8}

For a subcooled pool, the general equation for the decontamination factor is:

$$\ln(DF) = \ln[DF(H,0)] + a + b\Delta T + c\sqrt{\Delta T} + d\Delta T^{3/2}$$
$$+ eH\Delta T + f(H\Delta T)^{1/2} + gH^3\sqrt{\Delta T} + hH^{3/2} \tag{17}$$

where ΔT is the number of degrees of subcooling (K). Note that the first term in equation 17 is the result of equation 16.

The constants **a**, **b**, **c**, **d**, **e**, **f**, **g**, and **h** are shown in Table 2.2.3.1-2 for the different percentiles.

Table 2.2.3.1-2. Values for the constant used in equation 17 [Chapter 5, Po92]

Constant	Values		
	10th Percentile	50th Percentile	90th Percentile
a	0.00993606	-0.084381550	0.03437166
b	-0.0474108	-0.07040774	-0.2333505
c	0.5696997	0.8238286	1.4415216
d	0.0	0.0	0.01234607
e	0.0	0.0	$3.92396212 \times 10^{-4}$
f	0.0433372	0.0668004	0.075810892
g	0.0	0.0	1.3850581×10^{-8}
h	0.0	8.2346311×10^{-5}	0.0

2.2.3.2 Elemental Iodine Removal

The user may specify a table for the elemental iodine removal coefficient as a function of time. This removal coefficient should include the effects of reevolution of iodine once it is deposited because iodine reevolution is not explicitly modeled.

2.2.3.3 Organic Iodine Removal

The user may specify a table for the organic iodine decontamination factor as a function of time in an overlying pool.

2.2.4 Leakage

The user may specify the leakage between compartments or from a compartment to the environment compartment. No differentiation is made for different chemical groups or forms, thus all fission products leak at the same rate, with a removal efficiency of zero for all transport

groups. This is the commonly used method of releasing radionuclides to the environment. The primary routine for leakage phenomena is CIN.

2.2.5 Suppression Pools

Suppression pools are modeled as a pathway between two compartments. As material passes through the suppression pool, some portion of that material will be retained. The retention by the pool of aerosols and elemental and organic iodine is discussed in this section. Noble gases are assumed to not be affected by the presence of a suppression pool. The primary routine for suppression pool phenomena is SUPIN, which is called for the path into the pool; SUPOUT is called for the path out of the suppression pool and determines flow rates only.

2.2.5.1 Aerosol Removal

The user may specify a table for the aerosol decontamination factor and the volumetric flow rate into the suppression pool as a function of time. As those fission products that are in aerosol form move from one compartment to another through a suppression pool, the amount retained by the pool is related to the decontamination factor as given by equation 3. The aerosol decontamination factor is applied to iodine aerosols as well as aerosols from all other chemical groups.

2.2.5.2 Elemental Iodine Removal

The user may specify a table for the elemental iodine decontamination factor and the volumetric flow rate into in the suppression pool as a function of time. The elemental iodine retained is placed in the suppression pool.

2.2.5.3 Organic Iodine Removal

The user may specify a table for the organic iodine decontamination factor and the volumetric flow rate into the suppression pool as a function of time. The organic iodine retained is placed in the suppression pool.

2.2.6 Deposition in Piping

Piping is modeled as a transfer pathway where deposition can occur. A model is available for the removal of fission products during transport through pipes. Alternatively, the user may specify decontamination factors and volumetric flow rates as a function of time. Noble gases are assumed not to interact with the piping and are transmitted without any depletion. The primary routine for pipe deposition phenomena is PIPIN. The models chosen do not have documented limitations; however, the assumption is made that only primary deposition phenomena are being modeled. Scenarios in which supersaturated conditions occur, or in which very high or very low velocities are found, may give unrealistic results.

2.2.6.1 Brockmann Model for Aerosol Removal

The user may specify a table for the aerosol decontamination factor and a volumetric flow rate as a function of time for aerosols moving through the piping. Alternatively, the user may select the Brockmann model for deposition in pipes. The variation of the Brockmann model [Br91] used in RADTRAD only examines deposition in pipe bends and that due to settling, turbulent inertia, and diffusion. The primary routine for the Brockmann model of aerosol deposition in pipes is implemented in the routine BROCK.

The mean particle diameter, d_p, is assumed to be 1 μ with an average particle density, ρ_p, of 1000 kg/m^3. The temperature, pressure, open volume, and other parameters as noted below are provided by the user.

Particles will settle due to gravitational force and deposit on the horizontally projecting lower surface of the flow path during transport. This deposition efficiency, η_g, is modeled as:

$$\eta_g = 1 - \exp\left(-U_g A_s / \pi Q\right)$$
$$U_g = \tau g \tag{18}$$
$$\tau = d_p^2 \rho_p / 18 \mu$$

where:

U_g $=$ gravitational deposition velocity (m/s)

τ $=$ particle relaxation time (s)

Q $=$ user-provided pipe gas flow (m^3/s)

A_s $=$ user-provided total pipe surface area (m^2)

μ $=$ viscosity of air, 1.93×10^{-5} Pa-s

If the flow is turbulent, then turbulence in the central core can propel a particle into the laminar sublayer. If the particle inertia is high, then it will penetrate the sublayer and be collected on the wall. There have been experiments on inertial deposition velocity [Li.74] and Brockmann has modeled the turbulent deposition efficiency, η_{turb}, as:

$$\eta_{turb} = 1 - \exp\left(-U_t A_s / Q\right)$$

$$U_t = 0.01988 \, U_{air} / Re^{1/8} \tag{19}$$

$$Re = \rho_{air} \, U_{air} \, d_H / \mu$$

where:

U_t = turbulent inertial deposition velocity (m/s)

U_{air} = air velocity (m/s)

d_H = hydraulic diameter, 4 vol / A_s (m)

ρ_{air} = air density (kg/m^3)

When the flow is slower such that

$$\frac{\tau U_{air}}{d_H} Re^{3/4} < 326.6 \tag{20}$$

then the turbulent deposition velocity is

$$U_t = 1.861 \times 10^{-7} \left[\frac{\tau U_{air}}{d_H} \right]^2 U_{air} Re^{11/8} \tag{21}$$

Small particles undergoing Brownian diffusion will diffuse from areas of high concentration to those of low concentration. Since the wall acts like a sink for these particles, there is net diffusion from the bulk to the wall. This phenomenon has been analyzed [Go 49] and the diffusional deposition efficiency is modeled as:

$$\eta_{diff} = 1 - \exp\left(- U_{diff} A_s / Q\right) \tag{22}$$

In laminar flow, this efficiency is modeled as:

$$\eta_{diff} = 1.0 - 2.56 \zeta^{2/3} + 1.2 \zeta + 0.77 \zeta^{4/3} \tag{23}$$

$$\zeta = A_s D_{iff} / Q d_H \tag{24}$$

where

ζ = dimensionless diffusion parameter

D_{iff} = particle diffusion coefficient (m^2/s)

When the flow is slow or the pipe length is large such that $\zeta > 0.02$, then

$$\eta_{diff} = 0.819 \exp(-3.657\zeta) + 0.097 \exp(-22.3\zeta) + 0.032 \exp(-57\zeta)$$

In turbulent flow, the diffusional efficiency [Fr 77] is modeled as:

$$\eta_{diff} = 1 - \exp\left[-\zeta^{2/3} 0.0187 \, \mathrm{Re}^{13/24}\left(\frac{L}{d_H}\right)^{1/3}\right]$$ (25)

where:

L $=$ path length $= A_s / \pi d_H$ (m)

When the direction of gas flow is diverted in a bend, an aerosol particle may deviate from the gas flow due to its inertia and deposit on the wall. The efficiency of this process is modeled as:

$$\eta_{bend} = \frac{\tau \, U_{air} \, \varphi}{d_H}$$ (26)

where:

$\tau =$ particle relaxation time, equation 18

$\varphi =$ the user-provided sum of the angles the flow has been diverted (radians)

When the flow is turbulent, this efficiency [Pu 87] is modeled as

$$\eta_{bend} = 1.0 - \exp\frac{(-2.823 \, \tau \, U_{air}\phi)}{d_H}$$ (27)

Thus the total aerosol deposition efficiency is modeled as:

$$\eta_T = 1.0 - \left(1.0 - \eta_g\right)\left(1.0 - \eta_{turb}\right)\left(1.0 - \eta_{diff}\right)\left(1.0 - \eta_{bend}\right)$$ (28)

2.2.6.2 Bixler Model for Elemental Iodine Removal

The user may specify an elemental iodine decontamination factor and a volumetric flow rate as a function of time. Alternatively, the user may also select the Bixler model for deposition in pipes. With this model, the elemental iodine vapor is deposited with an efficiency, η_{ei}, as:

$$\eta_{ei} = 1 - \exp\left(-A_S U_{ei} / 100Q\right)$$ (29)

$$U_{ei} = 2809 / T - 12.5$$ (30)

where:

$T = $ gas temperature (K)

The Bixler model for elemental iodine vapor deposition is based upon the Cline [Cl 91] correlation and is implemented in the routine BIXLER1.

2.2.6.3 Bixler Model for Organic Iodine Removal

The user may specify an organic iodine decontamination factor and a volumetric flow rate as a function of time. Alternatively, the user may also select the Bixler model for deposition in pipes. With this model the organic iodine vapor is deposited with an efficiency, η_{oi}, as:

$$\eta_{oi} = 1 - \exp(-A_S U_{oi}/100Q) \tag{31}$$

$$U_{oi} = 2809/T - 19.30 \tag{32}$$

The Bixler model for organic iodine vapor deposition is based upon the Cline [Cl 91] results and is implemented in the routine BIXLER3.

2.2.7 Filters

The user may specify a flow and a table of the filter efficiencies (%) for the different transport groups and flow as a function of time. The model used for filtration assumes that the user-supplied fraction of material passing through the filter is retained. Thus, the decontamination coefficient is:

$$\lambda_{filter} = \left(\eta_{filter}\middle/100\right)F \tag{33}$$

where F is the volume-normalized flow rate (s^{-1}).

The material removed is retained by the filters. Noble gases are not filtered. This type of transport path is typically used for both filtered and unfiltered inflow into a compartment. For example, both the control room leakage inflow and filtered inflow use this model. The primary routines for filter phenomena are FILTIN for inlet filters and RECIRC for recirculating filters.

2.3 Consequence Analysis

The user provides the atmospheric relative concentrations (X/Q) for offsite locations, for example, the exclusion area boundary or the outer perimeter of the low population zone, and the control room. In addition, the breathing rates (BR) and the control room occupancy factors are provided by the user. No atmospheric transport modeling is performed by the code at this time. Typical values for atmospheric dilution can be calculated using the PAVAN [Ba 82] or ARCON model [Ra95]. The consequence models were implemented in routine DOSES.

2.3.1 Offsite Consequences Analysis

The dose to the hypothetical individual is calculated using the specified X/Qs and the amount of each nuclide released during the exposure period. The air immersion dose from each nuclide, n, in an environmental compartment is calculated as:

$$D_{c,n}^{env} = A_n \left(\frac{X}{Q}\right) DCF_{c,n} \qquad (34)$$

where:

$D_{c,n}^{env} =$ air immersion (cloudshine) dose due to nuclide n in the environment compartment (Sv)

$DCF_{c,n} =$ FGR 11 and 12 air immersion (cloudshine) dose conversion factor for nuclide n as discussed in Section 1.4.3.3 (Sv m^3 / Bq s)

$X/Q =$ user-provided atmospheric relative concentration (s / m^3)

$A_n =$ released activity of nuclide n (Bq)

The activity is related to the number of atoms of nuclide n as:

$$A_n = N_n \lambda_n \qquad (35)$$

where λ_n is the radiological decay constant for the nuclide as defined in equation 1.

The inhalation dose from each nuclide, n, is calculated as:

$$D_{i,n}^{env} = A_n \left(\frac{X}{Q}\right) BR\, DCF \qquad (36)$$

where:

$D_{i,n}^{env} =$ inhalation dose commitment due to nuclide n in the environment compartment (Sv)

$BR =$ user-provided breathing rate (m^3 / s)

$DCF_{i,n} =$ user-provided inhalation dose conversion factor for nuclide n as discussed in Section 1.4.3.3 (Sv/Bq)

2.3.2 Control Room Consequence Analysis

The dose to a hypothetical individual in the control room is calculated based on the time-integrated concentration in the control room compartment. The air immersion dose in the control room is:

$$D_{c,n}^{CR} = \int C_n(t)dt \left(DCF_{c,n} / G_F \right) \qquad (37)$$

where $C_n(t)$ is the instantaneous concentration of radionuclide n in the compartment. The Murphy–Campe [Mu74] geometric factor, G_f, relates the dose from an infinite cloud to the dose from a cloud of volume V as:

$$G_F = \frac{1173}{V^{0.338}}$$ (38)

The inhalation dose in the control room is:

$$D_{i,n}^{CR} = \int C(t)dt \left(\frac{BR \cdot OF \cdot DCF_{i,n}}{G_F} \right)$$ (39)

where OF = user-supplied occupancy factor

The time-dependent atmospheric relative concentration (X/Q) provided by the user for the control room intake locations. The inhalation dose conversion factors have been taken from the output file produced by the FGRDCF code that is based on FGR 11 and 12 and are detailed in Section 1.4.3.3.

2.4 Mathematical Solution Method

This section addresses the mathematical solution method used to ultimately calculate the doses at various locations. The numerical solution technique is discussed in Section 2.4.1. The transport and radioactive decay calculations are discussed in Sections 2.4.2 and 2.4.3, respectively.

2.4.1 Numerical Solution Technique

It is possible to define a single system of coupled ordinary differential equations (ODEs) that simultaneously represents all of the phenomena considered by the code. However, the size of this equation set, and the computational cost of its numerical integration, would make its implementation impractical on a PC. Significant economies of calculation time and computer memory size in RADTRAD are achieved by dividing the calculations into two parts: (1) transport and (2) radioactive decay.

The fundamental premise behind this approach ensures that during a time step of small enough duration, the interdependence of the two components of the calculations can be neglected. That is, the transport equations defining transfer of material between compartments during a calculational time step can be solved numerically <u>without</u> taking account of the radioactive decay and in-growth occurring over that period. Likewise, the radioactive decay and in-growth equations can be solved during a time step without considering the simultaneous phenomenon of transport between compartments. If the user is concerned with the assumption, the scenario can be tested by executing the code with 0.25, 1.0, 4.0, and normal time steps to observe the differences; Section 2.4.3 also discusses this effect.

The two types of calculations are performed alternately. That is, the code begins its integration over a time step by considering the effect of radioactive decay on the inventory of all compartments. After the consideration of radioactive decay for the time step, the code considers the effect of transport between compartments during that time step. This process of alternating between decay and transport is repeated until the specified end time is reached.

During the course of its numerical integration, the code keeps track of the number of atoms of each fission product nuclide in each compartment. Compartments in this sense include not just atmospheric volumes within the plant, but surfaces, pools, and filters as well. By tracking all atoms in this manner, conservation of mass can be verified.

2.4.2 Transport Calculations

The present application is known as an "initial value problem" for the solution of ODEs. Numerical solution of the transport equations is accomplished with a Laplace transform method. The advantage of this approach is its capability to use large time intervals. The key assumption is that there is no change in any phenomenon during a time step. Thus, the code synchronizes the time step with the user-supplied phenomena, resulting in very large time steps that are limited only by the maximum transport or decay coefficient. The primary disadvantage is that this numerical technique is not as well developed and therefore is not as available in software libraries as other solutions to "initial value problems" like the Runge–Kutta. It was determined that the use of a few intermediate time steps, to account for the effect of deposition and removal, yielded a numerically stable solution. Thus RADTRAD uses on the order of 200 time intervals to cross a 720-hr calculation. If the user chooses to use fewer time steps, then the estimation error will increase by about 10% for 10 time steps. If the user chooses to use more time steps, then the estimation error will decrease by a few percent for 2000 time steps. The time step selection was implemented in routines NECSTEP and AUTODT, and the user controls the input on screen 3000.

Equation 1 can be rewritten in terms of the constant coefficients over the time intervals as:

$$\frac{d}{dt} N^m_{group,i} = - C_{group,i} N^m_{group,i} + \sum_{\substack{j=1 \\ j \neq i}}^{L} C_{group,j} N^{-m}_{group,j} + R^m_{group,i} \tag{40}$$

where

$C_{group,i}$ =   coefficients corresponding to the bracketed terms on line 2 of equation 1 for each transport group in volume i

$C_{group,j}$ =   coefficients corresponding to the bracketed terms on line 3 of equation 1 for each transport group, and volume j

$R_{group,i}$ =   source terms from line 1 for transport group in volume i

Note that the term "transport groups" has been substituted for nuclides. To further reduce computation time, the equations were resolved in terms of four transport groups: noble gases, elemental iodine, organic iodine, and aerosols. These four groups transport differently, but all components of any one group act the same. This implies that all xenon and krypton isotopes will transport identically and that cesium, barium, and all other aerosol isotopes will transport identically. The user specifies the release fractions for the various types of iodine and therefore determines the mass within each transport group.

Equation (34) can be transformed into Laplace space as

$$s \, \overline{N}^m_{group,i} - N^m_{group,i}(t=0) = - C_{group,i} \overline{N}^m_{group,i} + \sum_{\substack{j=1 \\ j \neq i}}^{L} C_{group,j} \overline{N}^m_{group,j} + \frac{R^m_{group,i}}{s} \tag{41}$$

where s is the Laplace operator. This equation can be solved by inverting the coefficient matrix and then multiplying the constant terms. For the case of two components or volumes, the result is:

$$\begin{bmatrix} \overline{N}^m_{group,1} \\ \overline{N}^m_{group,2} \end{bmatrix} = \begin{bmatrix} (s + C_{group,1}) & - C_{group,1,2} \\ - C_{group,2,1} & (s + C_{group,2}) \end{bmatrix}^{-1} \begin{bmatrix} N^m_{group,1}(t=0) + \dfrac{R^m_{group,1}}{s} \\ N^m_{group,2}(t=0) + \dfrac{R^m_{group,2}}{s} \end{bmatrix} \tag{42}$$

As the number of compartments increases, the number of elements in the matrix increases by a factor of 4, to account for each transport group. If nuclides were used instead of transport groups, then this increase would be significantly larger for a comprehensive nuclide set. An alternative to the numerically costly matrix inversion is to solve the problem analytically. This implies a determination of the zeros in the transformed system of equations. Then, given the zeros, the solution in time will be determined by the residues at each pole. The residue is determined from the derivative in Laplace space as:

$$a_k = \frac{1}{(m-1)!} \frac{d^{m-1}}{ds^{m-1}} \left[(s-a_k)^m \, F(s) e^{st} \right] \Big|_{s=a_k} \tag{43}$$

The evaluation of the derivative can be performed numerically, that is, over many small time intervals, or it can be determined analytically. The analytic solutions, discussed in the following sections, have been derived and implemented for cases with up to 10 equivalent volumes in the routine RESADER. This limitation on equivalent volumes can be extended as the limitation on the number of compartments is extended. However, even for a model using all ten compartments, it is not expected that the equivalency limit (also called multiplicity) will be near 10. This is because the variations in the transport and removal coefficients from compartment to compartment that occur in real problems will ensure distinct roots. Only in very simple models, where there may be equivalent volumes with equivalent transport and removal coefficients, can most of the roots be equal.

The solution uses COENUM and ZEROD to determine the poles and XNUPDT to update the nuclide inventories. Within the code this combination is solved three times, the first with the old inventories in each volume, then with the added sources, and finally as a complete inventory plus source solution. Thus the code can relate the new nuclide distribution within each transport group to the old distribution plus any additional radionuclide releases. This is implemented in RADCALC.

2.4.2.1 Calculating the Transport and Removal Coefficients

This section describes the methodology for calculating the transport and removal coefficients, $C_{group,n}$ and $C_{group,n,m}$, discussed in the previous section. Separate sets of transport coefficients are calculated for each transport group (*group*). Most of the discussion below applies equally to all transport groups. For clarity, only when transport groups are treated differently will the separate transport groups be discussed. The remainder of this section uses the term "nuclide" to indicate all of the atoms, molecules, or particles of a transport group within a compartment or transport path.

2.4.2.1.1 Compartment Losses. Coefficients of the first form, $C_{group,n}$, represent the sum of losses for a group from the compartment n. Losses arise from compartment removal mechanisms: sprays, natural deposition, and recirculating filters; and from pathway transport mechanisms: piping, filtered pathways, suppression pools, and air leaks. (Losses are the sum of flows out of compartment n.) All loss coefficients are in units of s^{-1} and represent the instantaneous fraction of nuclides in compartment n lost per second, as shown in equation 40. These coefficients appear as positive coefficients in row n, column n (the diagonal) of the Laplacian coefficient matrix (see equation 42).

The removal coefficients for sprays and natural deposition are equal to the coefficients (λs) calculated by the models described in Section 2.2 for the user-selected the models, or to the user-defined removal coefficients if the user chose to define coefficients. For recirculating filters, the user specifies efficiencies for the recirculating filter and a flow rate. The coefficients for the recirculating filter are then calculated using equation 44. Note: there are no removal mechanisms for the noble gas transport group.

$$C_{group,n}^{rfilter} = \frac{r_{rfilter,flow}}{V_n} \times \frac{\eta}{100} \tag{44}$$

where:

$C_{group,n}^{rfilter}$ = recirculating filter removal coefficient

$r_{rfilter,flow}$ = recirculating filter volumetric flow rate

V_n = volume of compartment n

η = percent filter efficiency

The transport coefficients representing the flow out of compartment n are not transport group dependent. Some pathways remove nuclides from the flow (group dependent), but this is modeled by reducing the flow into the destination compartment (see compartment m below). It does not affect the flow out of compartment n.

The transport coefficient for air leakage is equal to the user-defined removal coefficients. The coefficients for piping, filtered pathways, and suppression pools are calculated using equation 45.

$$C_{group,n}^{pipe} = \frac{r_{pipe,flow}}{V_n}, \quad C_{group,n}^{pfilter} = \frac{r_{filter,flow}}{V_n}, \quad C_{group,n}^{pool} = \frac{r_{pool,flow}}{V_n} \tag{45}$$

where:

$C_{group,n}^{pipe}$ = piping transport coefficient

$C_{group,n}^{pfilter}$ = filtered pathway transport coefficient

$C_{group,n}^{pool}$ = suppression pool transport coefficient

$r_{pipe,flow}$ = piping pathway volumetric flow rate

$r_{filter,flow}$ = filtered pathway volumetric flow rate

$r_{pool,flow}$ = suppression pool volumetric flow rate

V_n = volume of compartment n

The sum of all the losses from compartment n, $C_{group,n}$, is equal to the sum of all of the compartment removal and pathway transport coefficients as shown by equation 46.

$$C_{group,n} = C_{group,n}^{spray} + C_{group,n}^{dep} + C_{group,n}^{rfilter} + \sum_{i=1}^{n'} C_{group,n}^{path,i} \tag{46}$$

where:

$C_{group,n}$ = pathway transport coefficient for total flow from compartment n

$C_{group,n}^{path,i}$ = i^{th} pathway transport coefficient from compartment n

n' = number of paths from compartment n

The loss coefficients are calculated by the COEFFS subroutine. When calculating compartment removal mechanisms, COEFFS calls RECIRC, XNTDEP, and SPRY to calculate removal coefficients for recirculating filters, natural deposition, and sprays, respectively. For calculating

pathway transport losses, COEFFS calls PIPOUT, FOUT, SUPOUT, and COUT for piping, filtered, suppression pool, and leakage pathways.

2.4.2.1.2 Compartment Gains. Coefficients of the second form, $C_{group,n,m}$, represent the sum of gains to compartment n from compartment m due to pathway transport. All gain coefficients are in units of s^{-1} and represent the instantaneous fraction of nuclides in compartment m transported to compartment n per second, as shown in equation 40. These coefficients appear as negative coefficients in row n, column m, of the Laplacian coefficient matrix (see equation 42).

The coefficients for pathway transport into compartment n are equal to the negative of compartment m's matching pathway transport loss coefficient, if there was no loss in the pathway itself. This is always true for the air leakage pathway as well as the noble gas transport group. It will also be true if the user specifies no removal for the other pathways.

If the user has specified that losses are to occur in the pathway or has selected a model that calculates the losses that occur, then the pathway coefficient from compartment m (the source compartment) must be multiplied by a transport efficiency factor that describes the fraction of material that makes it to compartment n (the destination compartment). For filters, the transport efficiency factor is equal to one minus the filter efficiency. For piping and suppression pool pathways, the transport efficiency is equal to one divided by the decontamination factor. These relationships are shown in equation 47. Note: these equations are valid in all cases except when compartment n is connected to the environment compartment via intake filters. This case is discussed below.

$$C_{group,n,m}^{pipe} = \frac{C_{group,m}^{pipe}}{DF_{group,pipe}}, \quad C_{group,n,m}^{pfilter} = C_{group,m}^{pfilter}\left(1 - \frac{\eta_{group,pfilter}}{100}\right),$$

$$C_{group,n,m}^{pool} = \frac{C_{group,m}^{pool}}{DF_{group,pool}}$$

(47)

where:

$C_{group,n,m}^{pipe}$ = piping transport coefficient for flow to compartment n from compartment m

$C_{group,n,m}^{pfilter}$ = filtered pathway transport coefficient for flow to compartment n from compartment m

$C_{group,n,m}^{pool}$ = suppression pool transport coefficient for flow to compartment n from compartment m

$DF_{group,pipe}$ = piping pathway decontamination factor

$\eta_{group,pfilter}$ = filtered pathway filter efficiency (%)

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$DF_{group,pool}$ = suppression pool volumetric decontamination factor

If compartment n is connected to the environment compartment via intake filters (at present this is the only method for transport out of the environment into another compartment), then a different algorithm must be used so that the relative atmospheric concentration (X/Q) at the intake of the air filter(s) can be taken into account. If the environment is compartment l, and a pathway exists from another compartment m into the environment, then the pathway transport from compartment m to compartment n is given by equation 48.

$$C_{group,n,m}^{path} = C_{group,l,m}^{path} \frac{X}{Q} \sum_{i=1}^{n'} \left[r_{flow,i} \left(1 - \frac{\eta_i}{100} \right) \right] \tag{48}$$

where:

$C_{group,n,m}^{path}$ = pathway transport coefficient for flow to compartment n from compartment m

$C_{group,l,m}^{path}$ = pathway transport coefficient for flow to compartment l (the environment) from compartment m

$r_{flow,i}$ = i^{th} intake filtered pathway volumetric flow rate

η_i = i^{th} intake filtered pathway percent filter efficiency

n' = number of intake filters from the environment to compartment n

This is repeated for all paths that flow into the environment over the sum of all of the intake filters. Because all direct pathways (pathways that do not exit out of the environment) must be known before the above equation can be calculated, RADTRAD calculates the coefficients for the indirect environment pathways last.

The sum of all of the gains from compartment m to compartment n, $C_{group,n,m}$, is equal to the sum of all of the direct pathways from compartment m to compartment n, and the sum of all of the indirect pathways through the environment as shown in equation 49.

$$C_{group,n,m} = \sum_{i=1}^{n'} C_{group,n,m}^{path,i} + \sum_{i=1}^{n''} \left\{ C_{group,l,m}^{path,i} \frac{X}{Q} \sum_{j=1}^{n'''} \left[r_{flow,j} \left(1 - \frac{\eta_j}{100} \right) \right] \right\} \tag{49}$$

where:

$C_{group,n,m}$ = pathway transport coefficient for total flow to compartment n from compartment m

$C_{group,n,m}^{path,i}$ = i^{th} pathway transport coefficient for flow to compartment n from compartment m

$C_{group,l,m}^{path,i}$ = i^{th} pathway transport coefficient for flow to compartment l (the environment) from compartment m.

$r_{flow,j}$ = j^{th} intake filtered pathway volumetric flow rate

η_j = j^{th} intake filtered pathway filter efficiency (%)

n' = number of direct paths from compartment m to compartment n

n'' = number of indirect paths through the environment, from compartment m to compartment n

n''' = number of intake filters from the environment to compartment n

The gain coefficients are calculated by the COEFFS subroutine. For calculating pathway transport gains, COEFFS calls PIPIN, FILTIN, SUPIN, and CIN for piping, filtered, suppression pool, and leakage pathways.

2.4.2.2 Calculating the Derivatives of the Reduced Transform

This section describes the methodology for calculating the derivatives of the reduced transform, $F(s)$. Recall that $F(s)$ is obtained by forming the product:

$$F(s) = (s - z_{den})^\mu X(s) \tag{50}$$

where $X(s)$ is the Laplace transform to be inverted, s is the Laplace transform variable, z_{den} is the denominator root in question, and μ is the multiplicity, the numbers of repetitions of the root.

Let $D(K)$ denote the value of the Kth derivative of $F(s)$ evaluated at $s = z_{den}$. The index K is assumed to range from a minimum value of zero, and the "zeroth" derivative $D(0)$ is assumed to be the value of $F(z_{den})$ itself. Thus

$$D(0) = F^{(0)}(z_{den}), D(1) = F^{(1)}(z_{den}), D(2) = F^{(2)}(z_{den}), \ldots, \tag{51}$$

$$D(K) = F^{(K)}(z_{den})$$

The superscript on F indicates the order of the derivative of $F(s)$ with respect to s.

The corresponding inverse transform, $x(t)$, is the sum of the residues for the denominator multiplicity μ under consideration. It can be expressed as follows:

$$x(t) = \sum_{K=0}^{\mu-1} \left[\frac{D(K)}{K!} \right] \exp(z_{den}\, t) \left[\frac{t^{\mu-K-1}}{(\mu - K - 1)!} \right] \tag{52}$$

2.4.2.3 Numerator Multiplicity of Zero

When the numerator multiplicity is zero, the sequence of derivatives $D(K)$ is calculated using an iterative method. First, the zeroth derivative $D(0)$ is evaluated. This is the same as the value of the reduced transform $F(s)$ evaluated at the denominator root z_{den} under consideration. It initializes the iteration. The expression is:

$$D(0) = \frac{\prod_K [Z_{den}(J) - Z_{num}(K)]}{\prod_L' [Z_{den}(J) - Z_{den}(L)]^{\mu L}} \tag{53}$$

The prime on the second product symbol ($\prod$) indicates that the case $L = J$ has been excluded. The first product is represented by the complex variable TOPVAL in the code, while the second one is represented by the complex variable BOTVAL.

Given the value of $D(0)$, the higher derivatives can be obtained by using an iterative method in which each higher derivative is a linear combination of all lower-order derivatives.

$$D(K) = \sum_{L=0}^{K-1} \frac{(K-1)!}{[(K-1-L)!L!]} G(K-L)D(L) \tag{54}$$

The sequence of quantities $G(K)$ is used to link any given derivative to derivatives of all lower orders. It is obtained by calling the complex function SUMPWR and multiplying:

$$G(K) = (-1)^{K-1}(K-1)! \; SUMPWR \tag{55}$$

Like the derivatives $D(K)$, $G(K)$ is a function of the Laplace transform variable s, which has been evaluated at $s = z_{den}$. The complex function SMPWR returns a value equal to the difference of two sums. The first sum is that of the inverse powers of $(s\text{-}z_{num})$ with s set equal to z_{den}. The power in question is n, the order of the derivative required. The second sum is that of the inverse powers of $(s\text{-}z_{den})$ with s set equal to z_{den}. Note that the powers in the second sum are weighted according to the multiplicities of the denominator roots.

$$SUMPWR = \sum_{K=1}^{N_{num}} [Z_{den}(J) - Z_{num}(K)]^{-n} - \sum_{K=1}^{N_{denm}} \mu(J)[Z_{den}(J) - Z_{num}(K)]^{-n} \tag{56}$$

The only terms to be included in the summations are those for which the root differences in the square brackets are not equal to zero. Thus, if $z_{den}(J)\text{-}z_{num}(K)$ is zero for some K, then that value of K should be excluded from the first summation. Likewise, if $z_{den}(J)\text{-}z_{den}(K)$ is zero for some K, then that K should be excluded from the second summation.

The integer N_{num}, appearing in the first summation, is the number of numerators, which is the same as the number of compartments. The integer N_{den}, appearing in the second summation, is

the number of distinct denominator roots. As noted earlier, the integer n appearing as an exponent in both summations is the order of the derivative desired.

2.4.2.4 Numerator Multiplicity Greater than Zero

When the numerator multiplicity (designated by v) is greater than zero, the sequence of derivatives $D(k)$ is calculated much the same way as before, but with an additional step. Initially, the reduced transform $F(s)$ is further reduced by factoring out the polynomial $(s\text{-}z_{num})^v$, where z_{num} is the numerator root that is equal to the denominator root z_{den} under consideration. Otherwise, the value of $F(s)$ at $s = z_{den}$ would vanish. The twice-reduced transform is designated as $FBAR(s)$.

The value of $FBAR(s)$ at $s = z_{den}$ is designated as the zeroth derivative $DBAR(0)$, which corresponds to $D(0)$ when the numerator multiplicity is zero ($v = 0$). In all cases, the value of $DBAR(0)$ can be expressed as follows:

$$DBAR(0) = \frac{\prod_{K}^{\prime}\left[Z_{den}(J) - Z_{num}(K)\right]}{\prod_{L}^{\prime}\left[Z_{den}(J) - Z_{den}(L)\right]^{\mu L}} \tag{57}$$

The prime on the first product symbol indicates that the factor involving the numerator root z_{num} has been excluded from the product. The prime on the second product symbol indicates that the case $L = J$ has been excluded. As before, the first product is represented by the complex variable TOPVAL in the code, while the second one is represented by the complex variable BOTVAL.

The calculations continue, as in the case when $v = 0$, for the higher derivatives $DBAR(K)$ and the derivative linking factors $GBAR(K)$. Thus for $K>0$:

$$DBAR(K) = \sum_{L=0}^{K-1} \frac{(K-1)!}{\left[(K-1-L)!\,L!\right]} GBAR(K-L)\,DBAR(L) \tag{58}$$

and also:

$$GBAR(K) = (-1)^{K-1}(K-1)!\ SUMPWR \tag{59}$$

Finally, the derivatives $D(K)$ are obtained from their counterparts $DBAR(K)$ for $v \le K$:

$$D(K) = \frac{K!}{\left[(K-v)!v!\right]} \tag{60}$$

2.4.3 Radioactive Decay Calculations

Simulation of nuclide decay in a computer model like RADTRAD required the use of the exponential decay law. Simulation of daughter in-growth is more involved and it is generally necessary to invoke one or more simplifying assumptions to keep the computational burden within reasonable bounds.

This section outlines an algorithm for implementing daughter in-growth along with parent decay within the dose-and-consequence model. It begins with a description of the simulation of decay without in-growth, followed by a description of the inclusion of in-growth.

The algorithm for daughter in-growth assumes that only one generation of daughters needs to be calculated per time step in order to provide a level of nuclide inventory accuracy commensurate with the other algorithms used in the code. This implies that the user must specify a time step commensurate with the accuracy desired when choosing daughter in-growth. The algorithm consists of two steps. In the first step, all parents undergo simple exponential decay. In the second, the decay products are apportioned to one generation of daughters. Thus ^{135}I with a half-life of 6.6 hr will decay and form ^{135}Xe and ^{135m}Xe. The decay of the ^{135m}Xe in 15 min to ^{135}Xe increases the cloudshine dose. Therefore, a time step of less than 6 hr is needed to estimate this dose.

2.4.3.1 Simulation of Decay without Daughter In-growth

The decay of nuclide parents is simulated by applying the expression for exponential decay. If the initial amount of the ith nuclide is N_i^o, then the amount at time t is given by the following expression:

$$N_i^t = N_i^o \exp(-\lambda_i t) \tag{61}$$

where λ_i is the radiological decay constant for the ith nuclide.

The decrease in the amount of the ith nuclide resulting from this decay process over the time step Δt is given by the expression:

$$\Delta N_i^t = N_i^{t-\sigma t} - N_i^t \tag{62}$$

and is always non-negative.

2.4.3.2 Simulation of Daughter In-growth

The quantity ΔN_i^t represents the amount of the ith nuclide that was lost during the decay time t. It is also the amount of the ith nuclide that has become available for in-growth into the corresponding daughter nuclides. This quantity is to be apportioned according to the values of the branching fractions of the daughters. The following algorithm has been adopted for simulating this in-growth process. It is simple and intuitive and does not require an extraordinary amount of computation.

Let the ith nuclide be the daughter that is being "fed" by ingrowth as a result of the decay of parent nuclides. Let the jth nuclide be one of the parents whose decay "feeds" the daughter. Finally, let the index k, which ranges from 1 to 3, denote the particular daughter associated with the jth nuclide (parent).

If the kth daughter of the jth nuclide is identical to the ith nuclide, then the amount of the ith nuclide is adjusted to the value N_i^{t+} according the following equation:

$$N_i^{t+} = N_i^t + BF_{j,k} \Delta N_j^t \qquad (63)$$

Here N_i^t is the amount of the ith nuclide remaining after decay and before in-growth, $BF_{j,k}$ is the branching fraction daughter isotope fraction of the kth daughter of the jth nuclide detailed in Section 1.4.3.2, and ΔN_i^t is the decrease in the amount of the jth nuclide as a result of decay.

2.5 References

[Br91] J.E. Brockmann, "Sampling and Transport of Aerosols," in *Aerosol Measurement: Principles, Techniques, and Applications*, K. Wilke and P. A. Baron, Eds., Van Nostrand Reinhold, New York, 1991.

[Ba82] T.J. Bander, "PAVAN: An Atmospheric Dispersion Program for Evaluating Design Basis Accidental Releases of Radioactive Materials from Nuclear Power Stations," NUREG/CR-2858, PNL-4413, Pacific Northwest National Laboratory, Richland, WA, 1982.

[Cl91] J.E. Cline, "MSIV Leakage Iodine Transport Analysis", NRC-03-87-029, Nuclear Regulatory Commission, Washington, DC, 1991.

[Cr77] R. I. Crane and R. L. Evans, "Inertial Deposition of Particles in a Bent Pipe," *J. Aerosol Science*, 8 (1977): 161–170.

[Di62] J.J. DiNunno, R.E. Baker, F.D. Anderson, and R.L. Waterfield, "Calculation of Distance Factors for Power and Test Reactor Sites," TID-14844, U.S. Atomic Energy Commission, Washington, DC, 1962.

[Ep 87] M. Epstein and P. G. Ellison, "A Principle of Similarity for Describing Aerosol Particle Size Distributions," *J. Colloid and Interface Science*, 119 (1987).

[Fa84] Fauske & Associates, Inc., *FAI Aerosol Correlation*, An Industry Degraded Core Rulemaking (IDCOR) Program Report, Bethesda, MD, 1984.

Federal Guidance Report No. 11, "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion," EPA 520/1-88-020, Environmental Protection Agency, Washington, DC (1988).

Federal Guidance Report No. 12, "External Exposure to Radionuclides in Air, Water and Soil," EPA 420-r-93-081, Environmental Protection Agency, Washington, DC, 1993.

[Fr77] S.K. Friendlander, *Smoke, Dust, and Haze*, Wiley, New York (1977)

[Go49] P. G. Gormley and M. Kennedy, "Diffusion from a Stream Flowing Through a Cylindrical Tube," *Proc. Royal Irish Academy*, 52-A (1949): 163–169.

[Li74] B.Y.H. Liu and J. K. Agarwal, "Experimental Observation of Aerosol Deposition in Turbulent Flow," *J. Aerosol Science*, 5(1974): 145–55.

[Mu74] K. G. Murphy and K. M. Campe, "Nuclear Power Plant Control Room Ventilation System Design for Meeting General Design Criterion 19," *Proc. the 13th AEC Air Cleaning Conference*, CONF-740807, U.S. Atomic Energy Commission, Washington, DC, 1974.

[Ot86] J. M. Otter and E. U. Vaughn, "Evaluation of Aerosol Correlations," EPRI NP-4974, Rockwell International Corp., Canoga Park, CA, 1986.

[Po86] D. A. Powers, J. E. Brockmann, and A. W. Shiver, "VANESA: A Mechanistic Model of Radionuclide Release and Aerosol Generation During Core Debris Interactions with Concrete," NUREG/CR-4308, SAND85-1730, Sandia National Laboratories, Albuquerque, NM, 1986.

[Po92] D. A. Powers, and J. L. Sprung, "A Simplified Model of Aerosol Scrubbing by a Water Pool Overlying Core Debris Interacting with Concrete," NUREG/CR-5901, SAND92-1422, Sandia National Laboratories, Albuquerque, NM, 1992.

[Po93] D. A. Powers and S. B. Burson, "A Simplified Model of Aerosol Removal by Containment Sprays," NUREG/CR-5966, SAND92-2689, Sandia National Laboratories, Albuquerque, NM, 1993.

[Po95] D. A. Powers, K. E. Washington, S. B. Burson, and J. L. Sprung, "A Simplified Model of Aerosol Removal by Natural Process in Reactor Containments," NUREG/CR-6189, SAND94-0407, Sandia National Laboratories, Albuquerque, NM, 1995

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[Po97b] D. A. Powers, "Monte Carlo Uncertainty Analysis of Aerosol Behavior in the AP600 Reactor Containment Under Conditions of a Specific Design-Basis Accident," NUREG/CR-6522, Sandia National Laboratories, Albuquerque, NM, 1997.

[Pu87] D. Y. H. Pui, F. Romay-Novas, and B. Y. H. Liu, "Experimental Study of Particle Deposition in Bends of Circular Cross Section," *Aerosol Science Technology* 7 (1987): 301–315.

[So95] L. Soffer, S.B. Burson, C.M. Ferrell, R.Y. Lee, and J.N. Ridgely, "Accident Source Terms for Light-Water Nuclear Power Plants," NUREG-1465, Nuclear Regulatory Commission, Washington, DC, 1995.

[Ra95] J.V. Ramsdell, C.D. Simone, and S.B. Smyth, "Atmospheric Relative Concentrations in Building Wakes," NUREG/CR-6331, PNL-10521, Pacific Northwest National Laboratory, Richland, WA, 1995.

[St 95] S.A. Stage, "Computer Codes for Evaluation of Control Room Habitability (HABIT): Draft, NUREG/CR-6210, PNL-10496, Pacific Northwest National Laboratory, Richland, WA, 1995.

USNRC [74] "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Boiling Water Reactors," Regulatory Guide 1.3, Revision 2, June 1974.

USNRC [74] "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Pressurized Water Reactors," Regulatory Guide 1.4, Revision 2, June 1974.

[WA91] K.E. Washington, K.K. Murata, R.G. Gido, F. Gelbard, N.A. Russell, S.C. Billups, D.E. Carroll, R.O. Griffith, and D.L.Y. Louie, "Reference Manual for the CONTAIN 1.1 Code for Containment Severe Accident Analysis," NUREG/CR-5715, SAND 91-0835, Sandia National Laboratories, Albuquerque, NM, 1991.

3 Quality Assurance

RADTRAD has been developed and tested in accordance with the requirements of ANSI/ANS-10.4-1987, "American National Standard Guidelines for the Verification and Validation of Scientific and Engineering Computer Program for the Nuclear Industry." In addition to the use of these programming standards, the following measures were undertaken to ensure program quality:

- Individual program elements that perform calculations have been tested independently. The tests include manual checking of representative calculations. The functioning of these elements was then rechecked in conjunction with tests of other program elements when RADTRAD was run.

- Program elements involved in data input were checked by writing input data to output files and comparing the data in the input and output files. This process also checked the storage and transfer of input data within RADTRAD.

- A series of test cases were run using the full RADTRAD code. These test cases exercised the range of program options. Input and output files for each of the test cases were examined for accuracy and consistency.

- The code was placed under configuration control at the beginning of the developer's code tests. Changes in the code during the tests were logged in the code of the program element that was changed.

- The code underwent 4 months of beta testing by potential users.

- A rigorous set of acceptance tests jointly developed by SNL, NRC, PNNL, and Innovative Technology Solutions Corp. (ITS) were applied to the initial release and to subsequent releases of RADTRAD.

Section 3.1 provides a description of the individual subroutine testing and integration into the RADTRAD code. Section 3.2 gives the results of the beta testing program. In that section, 30 comments/discrepancies were reported by the PNNL team and 20 were resolved. The resulting version of RADTRAD was run through a series of about 30 acceptance tests. The tests and the comparison with other calculations are presented in Section 3.3. Section 3.4 details the last phase of quality assurance, RADTRAD configuration control. Chapter 4 discusses the coding standards used.

3.1 Module and Integration Tests

Module and integration tests were performed on each module as it became available and each test is detailed in the following subsections. Input screen tests are not included in this list because they are not part of the technical solution.

3.1.1 AEROSOL

This subroutine determines the removal coefficient for aerosol in the containment based upon the Powers model discussed in Section 2.2.2.1.2. This routine performs two functions: selection of an appropriate subprogram for the reactor and accident sequence selected, and determination of the removal coefficient for an advanced PWR design that has a power rating other than 1800 MWt. A testing routine was developed that was called routine AEROSOL for two power ratings, three reactor designs, three bounding percentiles (lower, 10%; median, 50%; or high, 90%), and the possible accident sequences [design basis accident or severe accident (SA)]. The 270 time-dependent choices were:

Reactor Type	Bounding Percentile	Power Rating (MWt)	Accident Sequence	Time (hr)
PWR	10, 50, 90	1000	DBA and SA	0–720
		3000		
BWR	10, 50, 90	1500	DBA and SA	0–720
		3500		
APWR	10, 50, 90	1800	DBA	0–720
		3800		

The tests were successful from the point of view that the appropriate routines were called and the values returned gave reasonably smooth results when plotted. In addition, the APWR power increase cases caused the removal coefficients to increase in accordance with the theory given in Section 2.2.2.1.2. The routine AEROSOL calls PWRSA, PWRDBA, APWRDBA, BWRSA, or BWRDBA to generate the removal coefficients. All of these routines are programmed similarly, with the differences due only to the times and removal coefficient formulation detailed in the theory section.

3.1.2 APWRDBA

This subroutine determines the aerosol removal coefficient in the containment for an advanced pressurized water reactor during a design basis accident. The routine determines the average removal coefficient over the current time step. Table 2.2.2.1-5 details the variation of removal coefficient with time and the bounding percentile (lower, 10%; median, 50%; or high, 90%). The routine first determines the decontamination factor for the two phases of the accident release (gap and in-vessel) at the given time by following the equation set described in Section 2.2.2.1.2. It then determines the net decontamination factor by dividing the sum of the current releases by the sum of decontamination of each of those releases. With the current decontamination factor and

the value at the beginning of the step, the average removal coefficient is found and returned to routine AEROSOL.

There were no sample problems in the Powers documentation associated with advanced pressurized water reactors. The actual coding follows the coding for the PWRDBA routine that was compared with a sample problem.

The test cases were examined for both smoothness of the final answer (typically the residual fraction of the iodine in the containment was used as a measure) and for the absolute value of the phase-dependent decontamination coefficient as detailed in the Powers document. Within the limits of the tests, 100.0 < Power < 4000 MWt, the answers were reasonable. As for the decontamination of all chemical species based upon the iodine decontamination, because iodine releases a larger fraction during the first two periods than the other species, the results of using the iodine removal coefficient are slightly nonconservative due to the slightly higher decontamination factor. However, the iodine is the most important radiologically and will therefore be more important to the final dose calculation.

3.1.3 AUTODT

This subroutine determines the next time step based on user-specified events and a manual time step control provided by the computer screen. The AUTODT subroutine was tested by being used during the acceptance test phase of the program.

3.1.4 BIXLER1

This subroutine calculates the decontamination coefficient for elemental iodine in a pipe as discussed in Section 2.2.6.2. It assumes that revaporization is negligible. It is called by the pipe deposition controlling the routine PIPINB.

Subroutine BIXLER1 is one of a package of subroutines that were developed as an alternative to the MSIV code for steam pipes. The other components of the package are BROCK and BIXLER3.

The purpose of BIXLER1 is to determine the transport efficiency, and thus the decontamination factor, for elemental iodine in the steam pipes. All the relevant information was detailed in Section 2.2.6.2.

The only reference is an internal memo, dated August 29, 1995, from N. E. Bixler [Bi95], which references the Cline report [Cl91].

Testing:

Subroutine BIXLER1 was first tested off-line. User-specified values were provided for the flow rate, temperature, and pressure of the vapor. The transport efficiency was obtained from the Cline correlation, and the decontamination factor was obtained as its reciprocal. The resulting values

were compared with the curves in the Cline report. The subroutine was then integrated into RADTRAD and the results compared with HABIT calculations in acceptance tests 13 and 14.

Note on revaporization:

Revaporization is neglected in the Bixler model for the following reason. It is assumed that at the beginning of the break, the pressure and temperature are high. Under these circumstances, revaporization is not an issue. As the accident progresses, the pressure and temperature will decrease monotonically. Under these circumstances, revaporization will occur only when both pressure and temperature are low, that is, near standard conditions. By this time, the rate of flow will also be very low, so the effects of revaporization will not have a significant impact.

3.1.5 BIXLER3

This subroutine calculates the decontamination coefficient for organic iodine in a pipe as discussed in Section 2.2.6.3. It assumes that revaporization is negligible. It is called by the routine controlling pipe deposition PIPINB.

Subroutine BIXLER3 is one of a package of subroutines that were developed as an alternative to the MSIV code for steam pipes. The other components of the package are BROCK and BIXLER1.

The purpose of BIXLER3 is to determine the transport efficiency and thus the decontamination factor for organic iodine in the steam pipes. All the relevant information was detailed in Section 2.2.6.3.

The only reference is an internal memo, dated August 29, 1995, from N. E. Bixler [Bi95], which references the Cline report [Cl91].

Testing:

Subroutine BIXLER3 was first tested off-line. User-specified values were provided for the flow rate, temperature, and pressure of the vapor. The transport efficiency was obtained from the Cline correlation, and the decontamination factor was obtained as its reciprocal. The resulting values were compared with the curves in the report. The subroutine was then integrated into RADTRAD and the results compared with HABIT calculations in acceptance tests 13 and 14.

3.1.6 BROCK

This subroutine calculates the transport efficiency of aerosols for piping pathways as discussed in Section 2.2.6.1. The subroutine assumes continuous flow from the pipe inlet. It is based upon a lumped-node model description [Br91]. Subroutine BROCK includes the following effects:

1. gravitational settling, for low-flow-rate conditions;
2. turbulent inertial deposition, along straight pipe sections;
3. Brownian diffusion, along straight sections of pipe; and

4. inertial deposition in bends.

It is called by the routine controlling pipe deposition, PIPINB. Subroutine BROCK is one of a package of subroutines that were developed as an alternative to the MSIV code for steam pipes. The other components of the package are BIXLER1 and BIXLER3.

The purpose of BROCK is to determine the transport efficiency and thus the decontamination factor for aerosols in the pipes. This subroutine considers gravitational settling, Brownian diffusion, turbulent inertial deposition, and inertial deposition at bends.

Program DRIVER was created to test subroutine BROCK. It passed the following user inputs to BROCK:

tube inner surface area	$6.8101E+05$ cm^2
tube volume	$1.2108E+07$ cm^3
flow rate	$1.416E+06$ cm^3/s
gas temperature	356.0 K
gas pressure	40.0 atm
bend angle	90 degrees
length/diameter	1, 10, 100
tube/diameter	0.01, 0.1, 1.0 m
gas velocity	0.01, 0.1, 1/0 m/s
gas temperature	300, 500, 700, 900 K
gas pressure	1, 2 atm.
particle size	0.1, 0.2, 0.4, 0.8, 1.6, 3.2, 6.4, 13.0, 26.0, and 52 microns

Additional parameters were derived from these. The total transport efficiency ranged from 0.0 (all aerosol would be deposited) to 1.0 (no aerosol would be deposited). The most significant deposition phenomenon was due to gravitational settling. At the higher flows and shorter lengths, the deposition due to bend was important. The diffusiophoretic had some effect for the smaller particles. The logic can be easily modified to allow the user to determine mean aerosol diameter. The current version assumes a 1-micron particle size. In addition to these results, the subroutine also provided the deposition velocity.

3.1.7 BWRDBA

This subroutine determines the aerosol removal coefficient in the containment for a boiling water reactor during a design basis accident. This subroutine determines the average removal coefficient over the current time step. Table 2.2.2.1-4 details the variation of removal coefficient with time, reactor thermal power, and bounding percentile (lower, 10%; median, 50%; or high, 90%). This subroutine first determines the decontamination factor for the two phases of the accident release (gap and in-vessel) at a given time by following the equation set described in Section 2.2.2.1.2. It then determines the net decontamination factor by dividing the sum of the current releases by the sum of decontamination of each of those releases. With the current decontamination factor and the value at the beginning of the step, the average removal coefficient is found and returned to routine AEROSOL.

There were no sample problems in the Powers documentation associated with boiling water reactors. The actual coding follows the coding for the PWRDBA routine, which was compared with a sample problem.

The test cases were examined for both smoothness of the final answer (typically the residual fraction of the iodine in the containment was used as a measure) and for the absolute value of the phase-dependent decontamination coefficient as detailed in the Powers document. Within the limits of the tests, 100.0 < Power < 4000 MWt, the answers were reasonable. For the decontamination of all chemical species based upon the iodine decontamination, because iodine releases a larger fraction during the first two periods than the other species, the results of using the iodine removal coefficient are slightly nonconservative due to the slightly higher decontamination factor. However, the iodine is the most radiologically important and will therefore be more important to the final dose calculation.

3.1.8 BWRSA

This subroutine determines the aerosol removal coefficient in the containment for a boiling water reactor during a severe accident. This subroutine determines the average removal coefficient over the current time step. Table 2.2.2.1-3 details the variation of removal coefficient with time, reactor thermal power, and bounding percentile (lower, 10%; median, 50%; or high, 90%). This subroutine first determines the decontamination factor for each phase of the accident release (gap, in-vessel, ex-vessel, and late in-vessel) at the given time by following the equation set described in Section 2.2.2.1.2. It then determines the net decontamination factor by dividing the sum of the current releases by the sum of decontamination of each of those releases. With the current decontamination factor and the value at the beginning of the step, the average removal coefficient is found and returned to the routine AEROSOL.

There were no sample problems in the Powers documentation associated with boiling water reactors. The actual coding follows the coding for the PWRSA routine, which was compared with a sample problem.

The test cases were examined for both smoothness of the final answer (typically the residual fraction of the iodine in the containment was used as a measure) and for the absolute value of the phase-dependent decontamination coefficient as detailed in the Powers document. Within the limits of the tests, 100.0 < Power < 4000 MWt, the answers were reasonable. For the decontamination of all chemical species based upon the iodine decontamination, because iodine releases a larger fraction during the first two periods than the other species, the results of using the iodine removal coefficient are slightly nonconservative due to the slightly higher decontamination factor. However, iodine is the most radiologically important and will therefore be more important to the final dose calculation.

3.1.9 CIN

Subroutine CIN calculates the normalized flow into the compartment due to natural convection (air leakage). The user specifies the compartment volume and the volumetric flow rate between the compartments. These values are returned in CLIN(4).

Four values were provided for the convection flow rate. These were specified at time markers 0.0, 1.0, 2.0, and 3.0 hr. The simulation time was taken to be 1.5 hr. The subroutine returned the correct values during this test.

3.1.10 COEFFS

Subroutine COEFFS combines the coefficients for the activated removal and transport mechanisms to obtain the system matrix for the matrix differential equation governing nuclide removal and transport. Subroutine COEFFS calls as many as eleven subroutines to obtain the removal/transport contributions due to the various removal and transport mechanisms simulated by RADTRAD. These are as follows:

for removal within a compartment:
RECIRC - recirculation filters
XNTDEP - natural deposition onto surfaces
SPRY - compartment sprays

for removal by way of a pathway:
PIPOUT - flow out by way of a piping pathway
FOUT - flow out by way of a filtered pathway
SUPOUT - flow out by way of a suppression pool
COUT - flow out by way of natural convection

for gain by way of a pathway:
PIPIN - flow in by way of a piping pathway
FILTIN - flow in by way of a filtered pathway
SUPIN - flow in by way of a suppression pool
CIN - flow in by way of natural convection

Dummy versions of these subroutines were created for testing COEFFS. Each one returned preset values for removal or transport coefficients, without performing any calculations.

Testing:

The following test problems used a facility model consisting of two compartments with one pathway leading from compartment 1 to compartment 2:

00 no removal, no transport
01 recirculation filter in compartment 1
02 natural deposition in compartment 1
03 sprays in compartment 1

04 recirculation filter in compartment 2
05 natural deposition in compartment 2
06 sprays in compartment 2
07 piping flow, pathway 1
08 filtered flow, pathway 1
09 suppression pool, pathway 1
10 natural convection, pathway 1
11 this test number was not used.
12 all removal mechanisms in both compartments

The following test problems involved a facility consisting of two compartments with four pathways:

13 all four transport methods from compartment 1 to 2
14 all four transport methods from compartment 2 to 1

The following test problem involved a facility consisting of two compartments with eight pathways:

15 all removal mechanisms in both compartments,
    all four transport methods from compartment 1 to 2
    all four transport methods from compartment 2 to 1

The following test problem involved a still more complex facility.
16 three compartments with four pathways,
    one (distinct) removal mechanism for each compartment,
    pathway 1 from compartment 1 to compartment 2, piping
    pathway 2 from compartment 2 to compartment 1, filter
    pathway 3 from compartment 1 to compartment 3, s-pool
    pathway 4 from compartment 3 to compartment 1, natural convection

In every case, subroutine COEFFS retrieved the correct removal or transport coefficient and inserted it into the correct row and column of the system matrix.

3.1.11 COENUM

Subroutine COENUM computes the coefficients of the numerator polynomial in the Laplace transform of the transport group count. One such numerator exists for each compartment location.

This subroutine requires the Q-matrices obtained from subroutine INVMAT, as well as the initial quantities and release rates for each of the four transport groups in that compartment location.

The numerator polynomial $N(s)$ is a vector polynomial obtained by multiplying the matrix polynomial $Q(s)$ by the vector polynomial (s*x0+v0). Here s is the Laplace transform variable, x0 is the initial quantity of the transport group at each compartment location, and v0 is the

release rate for that transport group at each compartment location. Note that x0 and v0 are vectors.

The coefficients of the polynomial $N(s)$ are calculated in a sequential method:
$$N(k) = Q(k-1)*x0 + Q(k)*b, \text{ for } k=0 \text{ to } k=n$$
$$\text{with } Q(-1) = 0 \text{ and } Q(n) = 0.$$
Note that $N(k)$ is the coefficient of the term in $N(s)$ with factor $s**k$.

Testing:

Four tests were performed. In each one a system matrix was given and the output of the subroutine was compared with the results available as example problems. All tests were successful.

Test Case #1. Two compartments. Null system matrix.
```
0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00
```

Test Case #2. Two compartments. Robust system matrix.
```
0.1000E+01  0.2000E+01
0.3000E+01  0.4000E+01
```

Test Case #3. Three compartments. Robust system matrix.
```
0.0000E+00 -0.1000E+01 -0.1000E+01
0.1000E+01 -0.2000E+01 -0.1000E+01
0.0000E+00  0.0000E+00 -0.2000E+01
```

Test Case #4. Five compartments. Robust system matrix.
```
 0.1000E+01  0.0000E+00  0.2000E+01  0.4000E+01 -0.3000E+01
 0.0000E+00  0.4000E+01  0.0000E+00  0.1000E+01  0.4000E+01
 0.1000E+01  0.0000E+00  0.5000E+01  0.2000E+01  0.3000E+01
-0.2000E+01 -0.1000E+01  0.0000E+00  0.1000E+01  0.4000E+01
 0.7000E+01  0.1000E+01  0.2000E+01  0.3000E+01  0.1000E+01
```

3.1.12 COUT

This subroutine calculates the removal coefficient for flow out of a compartment by way of a pathway as a result of natural convection (air leakage). The coefficients are returned in units of 1/s. The user must provide the convection flow rate as well as corresponding time markers.

Testing:

Four values of the convection flow rate were provided in units of 1/s. The subroutine returned the correct value of the removal coefficient.

3.1.13 DKNGRO

This subroutine calculates the radioactive decay and daughter in-growth for all nuclides. It is called from the main driver routine RADCALC.

Two types of tests were performed. In the first series, only the effect of radionuclide decay was verified. This was done by first comparing the no decay case with a decay fraction of zero. In this latter case, the radiological decay constant, as discussed in Section 2.4.3.1, was set to 0.0. The decay constant was then modified to examine radionuclide disappearance. In the second series of tests, the effect of daughtering was accounted for. All tests were successful.

In addition, acceptance cases 2 and 7 were successfully compared with HABIT runs. These cases also test the radioactive decay and daughter in-growth for all nuclides.

3.1.14 DOSES

The subroutine DOSES calculates the environment and control room doses for receptors located at user-defined locations (e.g., exclusion area boundary, low population zone, control room operator). The user supplies the X/Qs and breathing rates as a function of time for each location. The user also supplies the occupancy factors as a function of time for the control room. The subroutine is called from the main driver routine RADCALC.

Two types of tests were performed. In the first series, the compartment was varied, that is, either the control room, the environment, or a normal room was chosen using only the ^{131}I isotope. This verifies that the internal logic for location is valid. The second series varied the concentration of the nuclide and the number of nuclides in the problem to verify the dose calculation. In addition, all the acceptance test cases were successfully compared with HABIT runs on the basis of dose by location.

3.1.15 FILTIN

Subroutine FILTIN calculates the removal coefficient for filtering of incoming air. It provides a coefficient, measured in 1/s, for all four transport groups. It is assumed that this coefficient is zero for noble gases. For the other three transport groups, the user must specify the volume of the "from compartment," the flow through the filter, and the efficiency of the filter for each of these transport groups.

Testing:

For purposes of testing, the filtered pathway was taken to pass from compartment 2 to compartment 1. The volume of compartment 2 was taken to be 1.0E+05 m^3. The simulation time was taken to be 1.0 hr.

Five values were provided for the filter efficiencies. The time markers were taken to be 0.0, 1.0, 2.0, 3.0, and 4.0 hr. The filter flow rates were 100.0, 200.0, 300.0, 400.0 and 500.0 in appropriate units. The filter efficiencies for elemental iodine, organic iodine, and aerosols were taken to be 10.0, 20.0, 30.0, 40.0, and 50.0 percent. The subroutine returned the correct values in this test.

3.1.16 FOUT

Subroutine FOUT calculates the transport rate resulting from flow out of a compartment by way of a filter. The user must provide values of the normalized flow rate.

Testing:

Four values of the filter flow rate were specified along with corresponding time markers. The subroutine returned the correct value in this test.

3.1.17 INITALL

Subroutine INITALL makes a sequence of calls to other subroutines that perform input and output functions. These include:

PMFOUT - output plant model file data

RDNUCD - read nuclide data

RD_NIF - read nuclide inventory file

NIFOUT - output nuclide inventory file

RDINPD - read dose conversion factor file

Testing consisted of checking to see that all referenced subroutines were properly called.

3.1.18 INVMAT

This subroutine uses Leverrier's algorithm, also called Fadeeva's method, for evaluating the resolvent matrix for a given system matrix. If A is the system matrix, I is the identity matrix, and s is the Laplace transform variable, then the resolvent matrix is defined as the matrix inverse of $(sI-A)$.

The resolvent matrix is a strictly proper rational function of s. If the system matrix, A, is n-by-n, then the resolvent matrix can be expressed as:

$$I/(sI-A) = Q(s)/p(s),$$

where $Q(s)$ is the matrix polynomial:

$$Q(s) = Q[n-1]*s**(n-1)+Q[n-2]*s**(n-2)+...+Q[1]*s+Q[0],$$

and where $p(s)$ is the scalar polynomial:

$$p(s) = s**n+p[n-1]*s**(n-1)+...+p[1]*s+p[0].$$

Each $Q[i]$, with $i=0$ to $n-1$, is a constant n-by-n matrix.

The subroutine determines the matrices $Q[i]$ and the scalars $p[i]$ using an iterative method:

$$Q[i-1] = Q[i]*A + p[i]*I, \text{ for } i=1 \text{ to } i=n-1, \text{ where } Q[n-1] = I,$$

$$p[i] = -1/(n-i)*tr(Q[i]*A), \text{ for } i=0 \text{ to } i=n-1, \text{ where } p[n] = 1.$$

Testing:

Seven tests were performed. The system matrices used are listed below. In each case the subroutine correctly obtained the matrices $Q[i]$ and the scalars $p[i]$, as determined by available examples.

Test Case #1. Two compartments. Null system matrix.
```
0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00
```

Test Case #2. Two compartments. Diagonal system matrix.
```
0.4107E+00   0.0000E+00
0.0000E+00   0.4080E+00
```

Test Case #3. Two compartments. Diagonal system matrix.
```
0.3362E+00   0.0000E+00
0.0000E+00   0.2446E+00
```

Test Case #4. Two compartments. Diagonal system matrix.
```
0.6670E+00   0.0000E+00
0.0000E+00   0.6652E+00
```

Test Case #5. Two compartments. Robust system matrix.
```
0.1000E+01   0.2000E+01
0.3000E+01   0.4000E+01
```

Test Case #6. Three compartments. Robust system matrix.
```
0.0000E+00  -0.1000E+01  -0.1000E+01
0.1000E+01  -0.2000E+01  -0.1000E+01
0.0000E+00   0.0000E+00  -0.2000E+01
```

Test Case #7. Five compartments. Robust system matrix.
```
 0.1000E+01   0.0000E+00   0.2000E+01   0.4000E+01  -0.3000E+01
 0.0000E+00   0.4000E+01   0.0000E+00   0.1000E+01   0.4000E+01
 0.1000E+01   0.0000E+00   0.5000E+01   0.2000E+01   0.3000E+01
-0.2000E+01  -0.1000E+01   0.0000E+00   0.1000E+01   0.4000E+01
 0.7000E+01   0.1000E+01   0.2000E+01   0.3000E+01   0.1000E+01
```

3.1.19 LUPC1

The function LUPC1 performs a table lookup, based on user-specified data for the independent and dependent variables. The data are stored in one-dimensional arrays.

Testing:

Five values were specified for the independent variable (X) and five for the dependent variable (Y):

$X = (1.0, \quad 2.0, \quad 3.0, \quad 4.0, 5.0)$
$Y = (100.0, 200.0, 300.0, 400.0, 0.0)$

The first test consisted of allowing the value of the independent variable (X) to ramp up from a point below the specified range to a point above that range. The second test consisted of allowing the independent variable to ramp down, passing through all values in the first test, but in reverse. These two tests showed that the correct values of the dependent variable (Y) were obtained in every case.

Rampup test		Rampdown test	
x-value	y-value	x-value	y-value
0.0	0.0	6.0	0.0
0.5	0.0	5.5	0.0
1.0	100.0	5.0	0.0
1.5	100.0	4.5	400.0
2.0	200.0	4.0	400.0
2.5	200.0	3.5	300.0
3.0	300.0	3.0	300.0
3.5	300.0	2.5	200.0
4.0	400.0	2.0	200.0
4.5	400.0	1.5	100.0
5.0	0.0	1.0	100.0
5.5	0.0	0.5	0.0
6.0	0.0	0.0	0.0

3.1.20 LUPC2

The function LUPC2 performs a table lookup based upon the compartment number, as well as user-specified data for the independent and dependent variables. The data are stored in two-dimensional arrays.

Testing:

User-specified data were provided for compartment one. Five values were given for the independent variable (X) and five for the dependent variable (Y):

$X = (1.0, \quad 2.0, \quad 3.0, \quad 4.0, 5.0)$

Y = (100.0, 200.0, 300.0, 400.0, 0.0)

The first test consisted of allowing the value of the independent variable (X) to ramp up from a point below the specified range to a point above that range. The second test consisted of allowing the independent variable to ramp down, passing through all values in the first test, but in reverse. These two tests showed that the correct value of the dependent variable was obtained:

Rampup test		Rampdown test	
x-value	y-value	x-value	y-value
0.0	0.0	6.0	0.0
0.5	0.0	5.5	0.0
1.0	100.0	5.0	0.0
1.5	100.0	4.5	400.0
2.0	200.0	4.0	400.0
2.5	200.0	3.5	300.0
3.0	300.0	3.0	300.0
3.5	300.0	2.5	200.0
4.0	400.0	2.0	200.0
4.5	400.0	1.5	100.0
5.0	0.0	1.0	100.0
5.5	0.0	0.5	0.0
6.0	0.0	0.0	0.0

3.1.21 LUPL2

This is a lookup table function based upon the location number version of a lookup for two-dimensional arrays, xp and yp, for example, which are the control room occupancy factor and breathing rates.

Testing:

Five values were specified for the independent variable (X) and five for the dependent variable (Y):

X = (1.0, 2.0, 3.0, 4.0, 5.0)
Y = (100.0, 200.0, 300.0, 400.0, 0.0)

The first test consisted of allowing the value of the independent variable (X) to ramp up from a point below the specified range to a point above that range. The second test consisted of allowing the independent variable to ramp down, passing through all values in the first test, but in reverse. The correct values of the dependent variable (Y) were obtained in every case.

Rampup test		Rampdown test	
x-value	y-value	x-value	y-value
0.0	0.0	6.0	0.0
0.5	0.0	5.5	0.0
1.0	100.0	5.0	0.0
1.5	100.0	4.5	400.0
2.0	200.0	4.0	400.0
2.5	200.0	3.5	300.0
3.0	300.0	3.0	300.0
3.5	300.0	2.5	200.0
4.0	400.0	2.0	200.0
4.5	400.0	1.5	100.0
5.0	0.0	1.0	100.0
5.5	0.0	0.5	0.0
6.0	0.0	0.0	0.0

3.1.22 LUPP1

The function LUPP1 performs a table lookup based on user-specified data for the independent and dependent variables. The data are stored in one-dimensional arrays.

Testing:

Five values were specified for the independent variable (X) and five for the dependent variable (Y):

$$X = (1.0, \ 2.0, \ 3.0, \ 4.0, 5.0)$$
$$Y = (100.0, 200.0, 300.0, 400.0, 0.0)$$

The first test consisted of allowing the value of the independent variable (X) to ramp up from a point below the specified range to a point above that range. The second test consisted of allowing the independent variable to ramp down, passing through all values in the first test, but in reverse. These two tests showed that the correct values of the dependent variable (Y) were obtained in every case.

Rampup test		Rampdown test	
x-value	y-value	x-value	y-value
0.0	0.0	6.0	0.0
0.5	0.0	5.5	0.0
1.0	100.0	5.0	0.0
1.5	100.0	4.5	400.0
2.0	200.0	4.0	400.0
2.5	200.0	3.5	300.0
3.0	300.0	3.0	300.0
3.5	300.0	2.5	200.0
4.0	400.0	2.0	200.0

4.5	400.0	1.5	100.0
5.0	0.0	1.0	100.0
5.5	0.0	0.5	0.0
6.0	0.0	0.0	0.0

3.1.23 LUPP2

The function LUPP2 performs a table lookup based upon the pathway number, as well as user-specified data for the independent and dependent variables. The data are stored in two-dimensional arrays.

Testing:

User-specified data were provided for pathway one. Five values were given for the independent variable (X) and five for the dependent variable (Y):

$$X = (1.0, \ 2.0, \ 3.0, \ 4.0, 5.0)$$
$$Y = (100.0, 200.0, 300.0, 400.0, 0.0)$$

The first test consisted of allowing the value of the independent variable (X) to ramp up from a point below the specified range to a point above that range. The second test consisted of allowing the independent variable to ramp down, passing through all values in the first test, but in reverse. The results of these two tests showed that the correct value of the dependent variable was obtained:

Rampup test		Rampdown test	
x-value	y-value	x-value	y-value
0.0	0.0	6.0	0.0
0.5	0.0	5.5	0.0
1.0	100.0	5.0	0.0
1.5	100.0	4.5	400.0
2.0	200.0	4.0	400.0
2.5	200.0	3.5	300.0
3.0	300.0	3.0	300.0
3.5	300.0	2.5	200.0
4.0	400.0	2.0	200.0
4.5	400.0	1.5	100.0
5.0	0.0	1.0	100.0
5.5	0.0	0.5	0.0
6.0	0.0	0.0	0.0

3.1.24 NECSTEPS

This subroutine determines the minimum set of time steps that are necessary to capture all of the events and other system changes that are included in the user input. It is called from the main driver routine RADCALC.

3.1.25 OPOOL

This subroutine calculates decontamination factors for each of the four transport groups, resulting from an overlying pool. Both user-provided and model-developed decontamination factors are implemented in this routine. The model is discussed in Section 2.2.3.

Subroutine OPOOL calculates the decontamination factors for each of the four transport groups that result from the effects of an overlying pool. It is assumed that the DF for noble gases is always unity, i.e., there is no decontamination.

The effects considered by this subroutine only apply during the ex-vessel portion of the release. Accordingly subroutine STERM should call OPOOL only during this phase of the release. The logic was corrected to ensure that this was the case. The Powers/Sprung model [Po92] is an option for the case of the aerosol DF.

Testing:

Subroutine OPOOL was originally tested in June 1995 and then exhaustively tested in September 1995. The cases of no DFs and user-specified DFs were tested for the elemental iodine, organic iodine, and aerosol transport groups. The case of the Powers/Sprung DFs was tested for aerosols. For the latter, the output from subroutine OPOOL was checked against sample problem calculations provided in tabular and graphical formats in the reference document. The DFs obtained from subroutine OPOOL were in excellent agreement with those obtained by direct calculations using the formulas provided in the reference cited.

The following caveat should be noted with regard to very large values of the DFs. Even though the model may yield DFs that are on the order of 1000 and even considerably larger, such high values may not be realizable in actual practice. This is because other phenomena, which are not modeled, come into play and result in reverse decontamination effects. See the caption to Figure 19 on page 66 of the Power reference.

Verification:

The model was independently verified as being consistently coded.

3.1.26 PIPIN

This subroutine calculates the removal rate for material flowing into a compartment by way of a pipeway as discussed in Section 2.2.6. The user may specify the flow rate for iodine and aerosol transport groups. In addition, the user may specify the DFs for these same transport groups or request that they be obtained using the Brockmann/Bixler algorithms. They are called from the coefficient evaluation routine, COEFFS.

3.1.27 PIPOUT

This subroutine calculates the normalized flow out of the given compartment by way of piping for all four transport groups. It is called from the coefficient evaluation routine, COEFF.

3.1.28 PWRDBA

This subroutine determines the aerosol removal coefficient in the containment for a pressurized water reactor during a design basis accident. The routine determines the average removal coefficient over the current time step. Table 2.2.2.1-1 details the variation of the removal coefficient with time, reactor thermal power, and bounding percentile (lower, 10%; median, 50%; or high, 90%). The routine first determines the decontamination factor for the two phases of the accident release (gap and in-vessel) at the given time by following the equation set described in Section 2.2.2.1.2. It then determines the net decontamination factor by dividing the sum of the current releases by the sum of decontamination of each of those releases. With the current decontamination factor and the value at the beginning of the step, the average removal coefficient is found and returned to routine AEROSOL.

The test case of 3000 MWt and median probability at 10 hr was used as a verification point because this case was used as example 3 in the Powers document. The code gave an average decontamination coefficient of 0.09666 whereas the document shows the value to be 0.0967. This case should be more accurate than the preceding one because there were only two release periods and both had the release fractions that were used in the code.

The other test cases were examined for both smoothness of the final answer (typically the residual fraction of the iodine in the containment was used as a measure) and for the absolute value of the phase dependent decontamination coefficient as detailed in the Powers document. Within the limits of the tests, 100.0 < Power < 4000 MWt, the answers were reasonable for the decontamination of all chemical species based upon the iodine decontamination. Because the iodine releases a larger fraction during the first two periods than the other species, the results of using the iodine removal coefficient are slightly non-conservative due to the slightly higher decontamination factor. However, the iodine is the most radiologically important and will therefore be more important to the final dose calculation.

3.1.29 PWRSA

This subroutine determines the aerosol removal coefficient in the containment for a pressurized water reactor (PWR) during a severe accident. This subroutine determines the average removal coefficient over the current time step. Table 2.2.2.1-2 details the variation of the removal coefficient with time, reactor thermal power, and bounding percentile (lower, 10%; median, 50%; or high, 90%). This subroutine first determines the decontamination factor for each phase of the accident release (gap, in-vessel, ex-vessel, and late in-vessel) at the given time by following the equation set described in Section 2.2.2.1.2. It then determines the net decontamination factor by dividing the sum of the current releases by the sum of decontamination of each of those releases. With the current decontamination factor and the value at the beginning of the step, the average removal coefficient is found and returned to routine AEROSOL.

The test case of 3000 MWt and median probability at 10 hr was used as a verification point because this case was used as example 2 in the Powers document. The code gave an average decontamination coefficient of 0.1097 whereas the document shows the value to be 0.1005.

Note, however, that the author assumes that at 10 hr after the start of the accident only 6.2 hr of the late in-vessel release have passed. In the final NUREG-1465 document, 8.2 hr would have passed and in addition the release fractions are slightly different. When these changes are made, the code and the document give almost identical results. The results were also compared with Figure 57 of the Powers document and gave the same results for all three bounding percentiles.

The other test cases were examined for both smoothness of the final answer (typically the residual fraction of the iodine in the containment was used as a measure) and for the absolute value of the phase-dependent decontamination coefficient as detailed in the Powers document. Within the limits of the tests, 100.0 < Power < 4000 MWt, the answers were reasonable for the decontamination of all chemical species, based upon the iodine decontamination. Because the iodine releases a larger fraction during the first two periods than the other species the results of using the iodine removal coefficient are slightly nonconservative due to the slightly higher decontamination factor. However, the iodine is the most radiologically important and will therefore be more important to the final dose calculation.

3.1.30 RADCALC

This is the main driver routine for the calculational aspects of RADTRAD. It calculates doses to receptors having locations defined by the user. Locations may be at the site boundary, in the low population zone, and in the control room.

3.1.31 RECIRC

This subroutine calculates the removal coefficient for each transport group due to the recirculating filter activated in a compartment. The user must specify the filter flow rate as well as the filter efficiencies for elemental iodine, organic iodine, and aerosols. It is assumed that no removal occurs for noble gases.

Testing:

The simulation time was taken to be 1 hr. Sets of four values for each filter parameter were defined. The time markers were taken to be 0.0, 1.0, 2.0, and 3.0 hr. The filter flow rates were set at 0.04, 0.03, 0.03, and 0.01 1/s. The efficiencies for elemental-iodine removal were 50.0, 45.0, 40.0 and 35.0%. Those for organic iodine and aerosols were the same. The subroutine provided the correct value for the removal coefficient for each of the four transport groups.

3.1.32 RESADER

Subroutine RESADER updates each transport-group quantity (XNGRP) at each compartment location for the current time step. The first three transport groups are returned in units of atoms (molecules), while the fourth is returned in kilograms.

The subroutine begins with the Laplace transform for the transport group quantity and uses the method of residues to invert the transform.

The most difficult aspect of the algorithm occurs when one or more zeros of the denominator occur repeatedly, that is, when their multiplicities are greater than unity. This necessitates the calculation of the derivatives of the transform.

Subroutine RESADER is an expanded version of RESIDUE that uses analytical expressions for the derivatives of the Laplace transform to determine the residues. It has a number of segments appended to it by way of include statements. These perform special functions as indicated below:

RESADER0.FOR reduces the set of denominator zeros to a list of
      distinct zeros and their corresponding multiplicities
RESADER1.FOR determines the residue for a denominator zero having multiplicity 1
RESADER2.FOR determines the residue for a denominator zero having multiplicity 2
RESADER3.FOR determines the residue for a denominator zero having multiplicity 3
RESADER4.FOR determines the residue for a denominator zero having multiplicity 4
RESADER5.FOR determines the residue for a denominator zero having multiplicity 5
RESADER6.FOR determines the residue for a denominator zero having multiplicity 6
RESADER7.FOR determines the residue for a denominator zero having multiplicity 7
RESADER8.FOR determines the residue for a denominator zero having multiplicity 8
RESADER9.FOR determines the residue for a denominator zero having multiplicity 9
RESADERX.FOR determines the residue for a denominator zero having multiplicity 10

Note that there are no segments to determine the residue for a denominator of zero having a multiplicity greater than 10. This should not be a problem as long as the number of compartments does not exceed 10, the current upper limit for RADTRAD.

The test problem sets were designed to test the ability of the subroutine to determine residues for denominator multiplicities up to and including 10, with numerator multiplicities up to one less than that of the denominator. For the sake of simplicity, the root in question was taken to be zero.

The following is a list of the actual test problem sets that were used. The Laplace transform $X(s)$ is the ratio of two polynomials, $N(s)$ and $D(s)$, each of which is a power of the variable s. The power of s in $D(s)$ is the same in the number of the test problem set and ranges from 1 to 10. The power of s in $N(s)$ ranges from 0 up to one less than the power of s in $D(s)$.

Test Problem Set 1:
  $X(s) = N(s)/D(s),$
  $D(s) = s,$
  $N(s) = 1$

Test Problem Set 2:
  $X(s) = N(s)/D(s),$
  $D(s) = s{**}2,$
  $N(s) = 1, s$

Test Problem Set 3:
  $X(s) = N(s)/D(s),$

$D(s) = s**3$
$N(s) = 1, s, s**2$

Test Problem Set 4:
$X(s) = N(s)/D(s),$
$D(s) = s**4$
$N(s) = 1, s, s**2, s**3$

Test Problem Set 5:
$X(s) = N(s)/D(s),$
$D(s) = s**5$
$N(s) = 1, s, s**2, s**3, s**4$

Test Problem Set 6:
$X(s) = N(s)/D(s),$
$D(s) = s**6$
$N(s) = 1, s, s**2, s**3, s**4, s**5$

Test Problem Set 7:
$X(s) = N(s)/D(s),$
$D(s) = s**7$
$N(s) = 1, s, s**2, s**3, s**4, s**5, s**6$

Test Problem Set 8:
$X(s) = N(s)/D(s),$
$D(s) = s**8$
$N(s) = 1, s, s**2, s**3, s**4, s**5, s**6, s**7$

Test Problem Set 9:
$X(s) = N(s)/D(s),$
$D(s) = s**9$
$N(s) = 1, s, s**2, s**3, s**4, s**5, s**6, s**7, s**8$

Test Problem Set 10:
$X(s) = N(s)/D(s),$
$D(s) = s**10$
$N(s) = 1, s, s**2, s**3, s**4, s**5, s**6, s**7, s**8, s**9$

3.1.33 SORTER

This subroutine does a sort on the elements of the real array passed to it and returns the sorted elements in the same array. Sorting means putting the elements in sequence, without eliminating duplications. The latter step is performed by subroutine NECSTEPS.

The elements in question are time markers that are defined by the scenario description. For example, the release timing file and user-input files both involve time markers.

For the purposes of testing, a set of 116 values was generated. First, the sequence 0.0, 1.0, 2.0, 3.0 was repeated 28 times, for a total of 112 values. Then the sequence 1.0, 2.5, 5.5, 15.5 was appended to it to yield a total of 116 elements. The subroutine successfully sorted these values.

3.1.34 SOURCE

This subroutine controls calculation of source material into each compartment. Source material arises from core heatup and degradation by the user's choice of inventory and release fractions. It is called from the main driver RADCALC and is discussed in Section 1.4.3. The subroutine provides RADTRAD with the total release rate for all transport groups into the compartment in question. It makes calls to STERM (source term).

Testing:

Four driver programs were developed to perform off-line testing of subroutine SOURCE. In all cases the function of subroutine STERM was simulated with the use of "dummy" subroutines. The first driver was designed to test the call to STERM, for the source term. A two-compartment model was used, with the source in the first compartment.

Off-line testing was followed by on-line testing in which SOURCE was integrated into RADTRAD and tested with PMF and SDF files.

3.1.35 SPRY

Subroutine SPRY determines the removal coefficients for all four transport groups due to the actions of compartment sprays. It is assumed that no removal effect occurs for noble gases. For the other three transport groups, the removal coefficient can be specified by the user.

For the aerosol transport group, the removal coefficient can also be calculated using the Powers mechanistic model [PO93]. This model requires that the user specify the following:

1. Q, the spray water flux, in m^3 $H_2O/m^2/s$
2. H, the fall height, in meters;
3. $ALPHA$, the ratio of unsprayed volume to sprayed volume,
4. PCT, the uncertainty percentile selected for the model (10th, 50th, 90th percentiles).

The model can handle both instantaneous "puff" releases and continuous releases. It should not be used for spray water fluxes and fall heights outside of specified ranges. For the spray water flux, this range is 1.0E-05 to 2.5E-03 m^3 $H_2O/m^2/s$. For the fall height, it is 5.0 to 50.0 m. In either case, if the specified value is out of range, then it will be reset to within range and a warning message will be written to the output file.

Testing:

Initial testing consisted of range checking on the spray water flux and fall height, as well as the uncertainty percentile and the fraction of aerosol suspended in the compartment atmosphere.

Additional testing was conducted in order to duplicate results provided in the report on the Powers model [Po93]. It was necessary to introduce a new subroutine SPINIT, which is called by NECSTEPS and which generates additional time markers when compartment sprays are active. It was also necessary to introduce an internal time-integration loop into the Powers model to provide acceptable accuracy in the removal coefficients for aerosols. With the addition of user time step control, this routine was removed from the code. The user should use values less than 0.1 hr while the spray is operational.

The test-data set that was used is shown below. All tests were successful.

Water (flux)	Fall (height)	Spray (alpha)	Uncert (percent)	Release (type)
0.0025	50	1.0	10%	instant
0.0025	50	1.0	50%	instant
0.0025	50	1.0	90%	instant
0.0025	50	1.0	10%	continuous
0.0025	50	1.0	50%	continuous
0.0025	50	1.0	90%	continuous

3.1.36 STERM

This subroutine calculates the nuclide release rates and the transport-group release rates from the core inventory to the source-term compartment. Release rates for transport groups (1) noble gases, (2) elemental iodine, and (3) organic iodine are given in units of atom/s. The release rate for transport group (4), aerosols, is in units of kg/s. The reference is NUREG-1465.

Testing:

For the purposes of testing, the PWR default values for release durations and fractions were used. Nine nuclides were included in the inventory, one from each nuclide family.

User-specified data were provided for overlying pool effects. It is assumed that there is no effect on noble gases. Tables of decontamination factors were provided for elemental iodine, organic iodine, and aerosols. In addition, fall heights (from 0.3 to 5.0 m), cooling temperatures (from 0 to 70 K), and an uncertainty percentile (10, 50, or 90%) were provided for the Powers model of aerosol removal.

Test runs were made for selected simulation times. The routine provided the correct results for each case.

0.25 hr	release phase #1
1.0	release phase #2
2.0	release phase #3
8.0	release phase #4
14.0	after release over

3.1.37 SUMPWR

This subroutine calculates the sum of the inverse numerator powers, minus the sum of the inverse denominator powers.

3.1.38 SUPIN

This subroutine calculates the removal coefficient for material flowing into a compartment through a suppression pool. The user must specify DFs for elemental iodine, organic iodine, and aerosols. It is assumed that there is no effect upon noble gases.

Testing:

Sets of four values of the DF and the flow rate were provided for elemental iodine, organic iodine, and aerosols. These were accompanied by corresponding time markers. The subroutine provides the correct values during this test.

3.1.39 SUPOUT

This subroutine calculates the normalized flow out of a given compartment by way of a suppression pool. The values obtained are returned in units of 1/s. It is assumed that there is no effect upon the noble gases. For the other three transport groups, the user must provide the flow rate versus time.

Testing:

A set of four values of the flow rate was provided for elemental iodine, organic iodine, and aerosols. Corresponding time markers were also provided. The subroutine returned the correct values during this test.

3.1.40 XNTDEP

This subroutine calculates the removal coefficient for natural deposition. The process of natural deposition includes many phenomena, such as gravitational settling, impaction, and diffusion. The removal coefficients are returned in units of 1/s.

The subroutine considers all four transport groups. However, natural deposition is considered applicable only to elemental iodine and to aerosols. Noble gases and organic iodine are nonreactive and so are not affected.

The removal coefficients for elemental iodine and aerosols can be specified by the user. In the case of elemental iodine, the user should include the effects of reemission of iodine, because this effect is not modeled explicitly.

The removal coefficients for aerosols can be calculated using a correlation by Henry [Fa84]. Henry indicates that the model can be used for any compartment, rather than just the source-term

compartment. To use the Henry correlation, the user must specify (1) the fall height in meters and (2) the particle density in kg/m^3. In both cases reference values are provided in data statements. For the fall height, this value is 5.0 m and for the sodium oxide (Na$_2$O) particle density, it is 2270.0 kg/m^3. In addition, there is a reference value for the total mass of aerosols in the volume, set at 6.0E-05 kg/m^3.

The removal coefficients for aerosols can also be calculated using a model by Powers [Po95]. This model applies only to the source-term compartment. To use it, the user must specify (1) the reactor type (PWR, AWR, BWR), (2) the accident type (design basis accident or severe accident), and (3) the uncertainty percentile (10%, 50%, 90%).

Testing:

Natural deposition of elemental iodine and aerosols was tested with user-specified coefficients. These tests were successful. Natural deposition of aerosols using the Henry correlation was tested by making use of tabulated data (Figure 1 on page 3) of reference Po95. Natural deposition of aerosols using the Powers model was tested off-line. See the testing report on AEROSOL.

3.1.41 XNUPDT

The function of subroutine XNUPDT is to convert transport-group quantities (XNRGP) into nuclide counts (XN). This is necessary because RADTRAD simulates removal and transport of transport groups, while doses are determined from nuclide counts.

Four transport-group quantities are provided:

XNGRP(1) = noble gases, atoms
XNGRP(2) = elemental iodines, atoms
XNGRP(3) = organic iodines, atoms (molecules)
XNGRP(4) = aerosols, kilograms

These are broken out into the nine nuclide families:

(1) noble gases, atoms
(2) iodines (elemental), atoms
   iodines (organic), atoms (molecules)
   iodines (aerosol), kilograms
(3) cesiums (aerosol), kilograms
(4) telluriums (aerosol), kilograms
(5) strontiums (aerosol), kilograms
(6) rutheniums (aerosol), kilograms
(7) lanthanums (aerosol), kilograms
(8) ceriums (aerosol), kilograms
(9) bariums (aerosol), kilograms

In turn, these are broken out into specific nuclide counts, all measured in atoms.

(1) Xe, Kr
(2) I, Br
(3) Cs, Rb
(4) Te, Sb, Se
(5) Sr
(6) Ru, Rh, Pd, Mo, Tc, Co
(7) La, Zr, Nd, Eu, Nb, Pm, Pr, Sm, Y, Am, Cm
(8) Ce, Pu, Np
(9) Ba

Testing:

For the purposes of testing, it was assumed that there were only nine nuclides, rather than the usual sixty provided for RADTRAD. One nuclide was selected from each nuclide family and the count for that nuclide was specified.

The following list indicates those nuclides, along with the transport groups to which they belong. Note that iodine is partitioned among three transport groups.

(1) ^{133}Xe   noble gas
(2) ^{131}I 1/3 elemental, 1/3 organic, 1/3 aerosol
(3) ^{134}Cs   aerosol
(4) ^{127}Te   aerosol
(5) ^{89}Sr   aerosol
(6) ^{58}Co   aerosol
(7) ^{90}Y   aerosol
(8) ^{141}Ce   aerosol
(9) ^{139}Ba   aerosol

The quantities for each of the four transport groups were then calculated and passed to the subroutine XNUPDT. There the above process was inverted, that is, the nuclide counts were recovered, based only upon the quantities of each transport group. This was done successfully for every nuclide count.

3.1.42 ZERODN

For each transport group, subroutine ZERODN determines:

(1) the zeros of the scalar denominator,
(2) the zeros of the vector numerator.

Subroutine ZERODN accepts the coefficients of the single denominator polynomial and the NC numerator polynomials of the Laplace transform of each of the four transport groups. The value of NC is the same as the number of compartments in the facility model.

The subroutine returns the NC+1 roots of the denominator polynomial and the variable number of roots for each of the NC numerator polynomials. It also returns the numbers of these roots and the leading coefficients of the numerator polynomials.

Subroutine ZERODN is called by RADCALC as part of a sequence of calls comprising the mathematics package of the program. Other subroutines to which it is related are INVMAT, COENUM, and RESADER. The extraction of the roots is performed with the IMSL routine DZPORC, which works with double-precision complex arrays.

Testing:

The arrays ZERODEN and ZERONUM contain the real or complex roots of the denominator and numerators, respectively. Tests were done with these arrays declared to be single-precision complex and double-precision complex. It was found that single precision was sufficient to provide accurate roots to RADCALC.

tightly clustered zeros

zeros are

$$(0.0, \quad 0.0 \quad)$$
$$(1.0E\text{-}6, 0.0 \quad)$$
$$(1.0E\text{-}6, 0.0 \quad)$$
$$(0.0, \quad 1.0E\text{-}6)$$
$$(0.0, \quad 1.0E\text{-}6)$$

coefficients are

$$p(0) = 0.0E\text{+}00$$
$$p(1) = -1.0E\text{-}24$$
$$p(2) = 0.0E\text{+}00$$
$$p(3) = 0.0E\text{+}00$$
$$p(4) = 0.0E\text{+}00$$
$$p(5) = +1.0E\text{+}00$$

Tests of the code for the extraction of denominator roots and numerator roots were performed with the following examples:

denominators

x^0	x^1	x^2	x^3	x^4	x^5
1	1				
1	-2	1			
-1	3	-3	1		
-6	11	-6	1		
1	-4	6	-4	1	
-1	5	-10	10	-5	1

numerators

x^0	x^1	x^2	x^3	x^4
0	0	0	0	0
0	0	0	0	1

```
0   0   0   1   0
0   0   0   1   1
0   0   1   0   0
0   0   1   0   1
0   0   1   1   0
0   0   1   1   1
0   1   0   0   0
0   1   0   0   1
0   1   0   1   0
0   1   0   1   1
0   1   1   0   0
0   1   1   0   1
0   1   1   1   0
0   1   1   1   1
1   0   0   0   0
1   0   0   0   1
1   0   0   1   0
1   0   0   1   1
1   0   1   0   0
1   0   1   0   1
1   0   1   1   0
1   0   1   1   1
1   1   0   0   0
1   1   0   0   1
1   1   0   1   0
1   1   0   1   1
1   1   1   0   0
1   1   1   0   1
1   1   1   1   0
1   1   1   1   1
```

3.1.43 ZPORC

This subroutine returns the double-precision or complex zeros of a given polynomial with double-precision coefficients. The required inputs are NDEG, the degree of the polynomial, and COEFF, the vector of the double-precision coefficients (with the zeroth power occurring first). The output is ZERO, the vector of double-precision or complex roots (whose number is NDEG).

3.1.44 ZRINV

This routine will zero the inventories in a particular type of compartment. This routine was written for general use, but currently is used only for environment compartments (compartment type = 3). The current use is to zero environment inventories for plume simulations.

3.2 Beta Testing Results

Beta testing of the RADTRAD code occurred from December 1995 through March 1996. During this time, 30 discrepancy reports were filed. Of the 30, 5 were in the critical category and were all corrected. An additional 10 discrepancy reports were in the important category; 9 have been corrected and 1 has not been corrected. The uncorrected discrepancy relates to a problem that can occur when shelling out to DOS from RADTRAD. Five discrepancy reports required no changes. The remaining 10 discrepancy reports were considered cosmetic changes; of these 10, 1 was corrected and the rest deferred. The following section gives the actual discrepancy reports.

3.2.1 Discrepancy Reports

See following pages.

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

When starting data entry, there should be some indication that it is not necessary to enter names for the .PMF and .SDF files unless an existing plant/scenario design is to be modified.

Evaluation:

Summary: _3_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: _ Current	_ New	
Code: _ Revise	✓ Defer	___ No Change Required
Documentation: _ User's Guide	_ Tech. Desc.	✓ No Documentation

Comments:
  Minimal effort required to change < 1h

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

If RADTRAD has been run, the names of the .PMF and .SDF files from the most recent runs should be used as defaults when RADTRAD is restarted. This would facilitate running a sequence of related scenarios.

Evaluation:

Summary: __3__   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope:	_ Current	_ New	
Code:	_ Revise	✓ Defer	_ No Change Required
Documentation:	_ User's Guide	_ Tech. Desc.	_ No Documentation

Comments:
Minimal effort to change < 1h

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

When a name is entered for the .PMF file, e.g. Name.PMF, the default names for the .SDF and output files should change automatically to Name.SDF and Name.TXT.

Evaluation:

The separation of the plant from the scenario information allows the user to run different scenarios for a given plant model. This capability precludes any for knowledge of what the scenario or output files might be called.

Summary: _5_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: _ Current   _ New

Code: _ Revise   _ Defer   ✓_ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
No correction necessary

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

Once plant compartments have been defined, it should be possible to define and redefine transfer pathways without losing the plant compartment definitions. RADTRAD appears to delete all data on unused compartments when it does calculations.

Evaluation:

An error during the effective volume calculations caused the wrong compartment to be altered. This error was corrected. Since that time the effective volume subroutine has been removed altogether.

Summary: _1_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: ✓ Current   _ New

Code: ✓ Revise   _ Defer   _ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
        Corrected.

    Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

When simplifying a scenario, RADTRAD doesn't delete transfer pathways correctly when the simplification is done by deleting compartments. Started with Acceptance Test Case 3 defining 4 compartments and 6 tx paths... saved .PMF file and exited. Restarted RADTRAD, recalled CASE3.PMF. Marked Air Filtration Volume unused, changed the Env. to AFV tx path to filtered path from Env to CR, marked the remaining tx paths associated with the AFV and the unfiltered path from the Env to CR as unused, then saved file as CASE3A.PMF. Transfer paths in CASE3A.PMF are not correct. Last 3 tx paths in CASE3.PMF dropped, not the correct 3. Files attached.

Evaluation:

This is a troublesome limitation of the user interface. It will be corrected for the help file version of RADTRAD.

Summary: _2_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: ✓ Current   _ New

Code: ✓ Revise   _ Defer   _ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
   Corrected

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

Is it possible to have RADTRAD calculate the outflow from the Control Room to the Environment from the inflow to ensure an air flow balance? This is a potential source of user error, particularly because the inflow can include both real and normalized flows.

Evaluation:

Flow balancing is not required in RADTRAD.

Summary: _5_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: _ Current   _ New

Code: _ Revise   _ Defer   ✓ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:

No Correction necessary.

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

When a radio button is used to select an option, the button should show the default option and it shouldn't be necessary to click on the button to select the default option (e.g. the select model buttons on the form used to edit transfer pathways in the scenario description). (This button doesn't add anything to the utility of RADTRAD does it? Perhaps the button should be deleted.)

Evaluation:

At present the buttons are necessary but there is almost certainly a better way to handle the input without requiring these buttons.

Summary: _3_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/29/96

Disposition:

Scope:	_ Current	_ New	
Code:	_ Revise	✓ Defer	_ No Change Required
Documentation:	_ User's Guide	_ Tech. Desc.	_ No Documentation

Comments:
Moderate effort to change < 1 d
> 1 h

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

RADTRAD requires numerical input in specific form (sometimes in normal floating point form and sometimes in scientific notation). Is this necessary. The program should accept any appropriate numerical values.

Evaluation:

This problem is a function of the Hi-Screen Pro II interface software. It requires you to specify if your real values are in regular or scientific notation. You can't specify both. This problem could be corrected if we wrote our own syntax checkers. This would not be a trivial task but the resulting interface would be better.

Summary: _3__   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: _ Current   _ New

Code: _ Revise   ✓ Defer   _ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
Significant effort to change < 1 wk
                        > 1 d

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

RADTRAD should accept input in engineering units used by NRC Staff. These units include flows in ft^3/min, leak rates in %/day, and volumes in ft^3. Unit conversion is a potential source of error and should be done by the program.

Evaluation:

The limitations of the High Screen Pro II interface software and screen size make this difficult to do with selectors or drop down lists. It could be done more easily by incorporating the units into the values themselves and having the syntax checker described in Report #8 do the necessary conversion. One drawback is that the user would have to enter units for all values in the non default units.

Units recommended by the NRC will be incorporated into RADTRAD version 2.12.

Summary: _2_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

      Scope: ✓ Current   _ New

      Code: ✓ Revise   _ Defer   _ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

      Comments:
        Corrected

      Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

There are too many data input forms... forms used to enter related information could be combined... the decay/ingrowth and iodine chemical form forms are an example...

Evaluation:
Much of the above problem can be contributed to the separation of plant and scenario information. It may be desirable to review this feature to determine whether or not it makes more sense just to use a single file per model. If so, then it would make sense to contain many of the plant and scenario screens.

Summary: _5_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: _ Current   _ New

Code: _ Revise   _ Defer   ✓ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
To make the above change would require a shift in the RADTRAD design philosophy that would in turn require extensive re-writing of the interface. This kind of change is beyond the normal scope of error correction or software maintenance and as such would require < change in the NRC requirements before it could be implemented. Since it would violate the requirement for separate plant and scenario files of information no change is presently required and in fact the codes would not meet NRC requirements if the change was made.

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

Delete writing the i/o unit status to the screen, if possible, for the RADTRAD production code.

Evaluation:
This debugging information has been removed.

Summary: _3_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope:	✓ Current	_ New	
Code:	✓ Revise	_ Defer	_ No Change Required
Documentation:	_ User's Guide	_ Tech. Desc.	_ No Documentation

Comments:
Corrected

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

Selecting decay and ingrowth should be 2 options.... Decay or no decay, and if decay is selected ingrowth or no ingrowth.

Evaluation:
The user has the capability of turning on decay for one, some, or all of the compartments. Because of this feature the user might possibly proceed through the problem setup first specifying daughter ingrowth before specifying any decay or turning all decay off and then turning decay back on. Either operation would have daughtering turned off when the user wanted it on. Daughtering has no effect if there is no decay.

Summary: _5_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

    Scope: _ Current   _ New

      Code: _ Revise   _ Defer   ✓_ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

    Comments:
        No correction necessary

    Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

RADTRAD needs better error trapping and messages to provide users with some information on what has gone wrong when the program fails. Before calculations are begun the program should check the input and identify errors and omissions that would cause the program to crash. This information should be provided to the user in an error message.

Evaluation:
Agreed Improvements have been made. See comments below.

Summary: _2_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: ✓ Current   _ New

Code: ✓ Revise   _ Defer   _ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
Corrected. Better error handling would improve the user's interaction with the software. But, while it is important it is not critical. Almost all errors in RADTRAD now print error information to the output file so the user can determine and correct the problem causing the error in most cases.

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

Occupancy factors should be input explicitly rather than requiring users to adjust X/Q or breathing rates. There isn't anything in the output that shows whether occupancy factor has been included or not.

Evaluation:
Occupying factors have been added.

Summary: 1   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: ✓ Current   _ New

Code: ✓ Revise   _ Defer   _ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
    Corrected.

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

With the TID source term it isn't normal practice for NRC to give credit for both an initial plateout of 50% of the iodine released and natural deposition. RADTRAD should provide an option to include or exclude the initial plateout.

Evaluation:
The TID source term specifies 50% release of iodine. Reg Guides 1.5 × 1.4 specify 50% plateout or an effective release of 25%. In cases where natural deposition in the containment is being modeled the user should use the TID_DEF.RFT file which has no plateout. Otherwise the user should use the TID_DBA.RFT which does.

Summary: 1   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: ✓ Current   __ New

Code: ✓ Revise   __ Defer   __ No Change Required

Documentation: __ User's Guide   __ Tech. Desc.   __ No Documentation

Comments:
  Corrected

Date: 3/19/96

RADTRAD β--Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

RADTRAD overwrites existing .PMF, .SDF, and .TXT files without warning. This can lead to unintentional loss of data. There should be a way to protect/unprotect these files, and there should be a warning prior to overwriting an unprotected file.

Evaluation:
This is indeed true and many users will expect and assume this kind of protection.

Summary: _3__   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: _ Current   _ New

Code: _ Revise   ✓ Defer   _ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
Moderate effort required to change < 1 d
                              > 1 h

Date: 3/19/96

RADTRAD β -Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

Using the DOS editor from within RADTRAD causes problems... out of memory errors routinely, and occasionally it screws up the cursor when displaying the results.

Evaluation:
A new browser has been written using the Hi-Screen Pro II features.

Summary: _2_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: ✓ Current	__ New	
Code: ✓ Revise	__ Defer	__ No Change Required
Documentation: __ User's Guide	__ Tech. Desc.	__ No Documentation

Comments:
   Corrected.

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

In one instance with bad input files, RADTRAD calculated and reported negative doses. Negative doses should not be reported.... If negative doses are calculated they should either be set to zero if they are the result of roundoff error, or the program should print an error message rather than the negative doses.

Evaluation:
This problem would be solved with better error handling in general. See report #13.

Summary: 2   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: ✓ Current   _ New

Code: ✓ Revise   _ Defer   _ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
Corrected. See Report #13

Date: 3/19/96

RADTRAD -Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 12/29/95

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

The output is excessive for normal use... There should be a separate summary table that gives cumulative doses as a function of time. This table should also include a summary of the input data, the code name and version, and the date and time that the code was run.

Evaluation:
The output has been vastly improved since Beta 1.03.

Summary: 2   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope:	✓ Current	_ New	
Code:	✓ Revise	_ Defer	_ No Change Required
Documentation:	_ User's Guide	_ Tech. Desc.	_ No Documentation

Comments:
    Corrected.

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 1/2/96

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

Selection of the dose factor/nuclide data values should be part of RADTRAD. Jay Lee suggests the following names for the 3 choices:

TID-14844/FGR 11 & 12
NUREG/1465/FGR 11 & 12
NUREG/1465/ICRP 60

Evaluation:
These are now selected at program startup. Note that the inventory selected for NUREG/1465 has nothing to do with NUREG/1465. It is the MACCS Sample inventory and is therefore referred to as the MACCS inventory.

Summary: 1 (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: ✓ Current   _ New

Code: ✓ Revise   _ Defer   _ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
Corrected.

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 1/2/96

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

RADTRAD crashes when bwr.nif or pwr.nif file is selected after selecting TID-14844/FGR 11 & 12 data file. There should be check for consistency in these files in RADTRAD if consistency is required by the program... The program should not crash leaving the user in the dark.

Evaluation:
I agree and the program should never crash. However, this problem isn't that disastrous. It will occur as soon as the user loads in his or her plant model file. This in itself should be a clear indication of what the problem was. Furthermore, because it happens immediately no user data has been lost.

Summary: _3_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope:	_ Current	_ New	
Code:	_ Revise	✓ Defer	_ No Change Required
Documentation:	_ User's Guide	_ Tech. Desc.	_ No Documentation

Comments:
Moderate effort to change < 1 d
                              > 1 h

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 1/2/96

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

Default TID Inventory is selected as default when MACCS BWR/PWR / FGR 11&12 nuclide file is selected prior to entering RADTRAD. Shouldn't default be the Default BWR or PWR? Similar comment related to the RF&T file default.

Evaluation:
Certainly would be helpful.

Summary: _3_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: _ Current   _ New

Code: _ Revise   ✓ Defer   _ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
Moderate effort to change < 1 d
                                    > 1 h

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 1/2/96

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

RADTRAD resets transfer rates to zero prior to calculations if a second time entry is not made for the transfer rate. Then RADTRAD crashes without giving user a clue to the problem. Second entries don't seem to be required for other parameters.

Evaluation:
All user defined inputs now accept a single input line. If the user indeed wants 0s then he or she does need to input a second line with a non-zero time so that RADTRAD will count the first line.

Summary: _2_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: ✓ Current   _ New

Code: ✓ Revise   _ Defer   _ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
    Corrected

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 1/2/96

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

The .pmf and .sdf files for TEST99 were initially created to check the effects of not including a second time for the transfer rate. The were then recalled and the data were edited so that the scenario should run. However, it didn't. I have not been able to identify the source of the problem. A more slightly more complex problem (TEST99A) was entered correctly the first time and runs OK. Both sets of .PDF and .SDF files are attached.

Evaluation:
See # 23

Summary: 2   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: ✓ Current   _ New

Code: ✓ Revise   _ Defer   _ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
   Corrected.

Date: 3/19/96

RADTRAD β-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 486DX2/50 MSDOS

Reported By: J.V. Ramsdell

Date: 1/2/96

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

User should be warned that after shelling to DOS, the directory must be reset to the subdirectory containing RADTRAD before returning to RADTRAD. Otherwise the program doesn't know what to do and ultimately crashes. Had to reboot the computer to get it to behave properly after this crash.

Evaluation:
It is unknown at this time what causes this problem but we will try to correct it in the helpfile versions.

Summary: _2_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/19/96

Disposition:

Scope: _ Current   _ New

Code: _ Revise   ✓ Defer   _ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
Actual time to correct unknown but highly improbable that it would resolve more than 1 d.

Date: 3/19/96

RADTRAD b-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 P5-90 MSDOS

Reported By: J.V. Ramsdell

Date: 1/10/96

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

The plant model in TEST.PMF is not good... compartments have been dropped, therefore there are pathways for compartments that don't exist. When TEST.PMF and TEST.SDF are used for calculations, RADTRAD stops and displays the message "Compartment Unused has an invalid type of 0." There is no response to the OK command button, and the CANCEL button appears to cause the program to try another calculation step. Finally, after several clicks on the CANCEL button, RADTRAD appears to come to a normal completion with the output file displayed in the editor. The results are all zero, but there should be a error exit when a problem occurs rather than having the program appear to run.

Evaluation:
The test.pmt and test.sdf files are no longer valid with newer versions of RADTRAD. If a user tries to read in such a file, the program gives an error message "invalid file format," and the user is forced to either type in a new file name or escape from the screen.

Summary: _5_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/25/96

Disposition:

Scope: _ Current   _ New

Code: _ Revise   _ Defer   _✓_ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
No corrections necessary

Date: 3/25/96

RADTRAD b-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 P5-90 MSDOS

Reported By: J.V. Ramsdell

Date: 1/19/96

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

Set decay on as default in all compartments.

Evaluation:
It is not clear whether or not this is desired by NRC. If it is then the change could be easily made. Any action on this discrepancy will have to be deterred until we get word from NRC or their preference.

Summary: _3_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/25/96

Disposition:

Scope: _✓_ Current   _ New

Code: _✓_ Revise   _ Defer   _ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
    Corrected. If decay is on, it is on for all compartments.

Date: 3/25/96

RADTRAD b-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 P5-90 MSDOS

Reported By: J.V. Ramsdell

Date: 1/19/96

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach *.pmf* and *.sdf* files if possible.

Set daughter ingrowth on as default and add text box indicating that ingrowth will not take place in those compartments where decay is turned off.

Evaluation:
No changes to the daughter ingrowth default can be made until the NRC determines what they want the default to be. The additional text should be added to the screens regardless of the daughtering default.

Summary: <u>_3_</u>   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/25/96

Disposition:

    Scope: <u>✓</u> Current   __ New

    Code: <u>✓</u> Revise   __ Defer   __ No Change Required

Documentation: __ User's Guide   __ Tech. Desc.   __ No Documentation

    Comments:
        Corrected. If decay and daughtering are on, then they are on for all compartments.

    Date: 3/25/96

RADTRAD b-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 P5-90 MSDOS

Reported By: J.V. Ramsdell

Date: 1/19/96

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

Add release timing files that do not include late in-vessel and ex-vessel releases.   These files should be the primary files used by RADTRAD.

Evaluation:
These files have been added. they are named as follows:

pwr_dba.rft
bwr_dba.rft

Summary: _2_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date: 3/25/96

Disposition:

       Scope: ✓ Current   _ New

       Code: ✓ Revise   _ Defer   _ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

    Comments:
       Corrected

    Date: 3/25/96

RADTRAD b-Test Discrepancy Report

RADTRAD Version: 1.03

Computer Type and Operating System: Gateway 2000 P5-90 MSDOS

Reported By: J.V. Ramsdell

Date: 3/5/96

Organization: PNNL

Telephone: (509) 372 6316

Problem or Requested Change: If a software problem is being reported, include a description of the input data that can be used to duplicate the problem. Attach .pmf and .sdf files if possible.

For dose calculations in the control room, the breathing rate and occupancy factor are combined into a single parameter. Thus, the occupancy factor is only applied to inhalation doses.   It is not applied in the calculation of the immersion (deep dose). Consequently doses to control room personnel may be significantly overestimated. This will be the case whenever there is a protracted release of noble gases and when recirculation filters are used to reduce the concentration of iodines and particulates in the control room. Suggest that a default breathing rate of 3.47E-4 be used in the control room and that the occupancy factor be entered by the user.

Evaluation:
Occupancy rates as well as breathing rates for control room doses may now be entered by the user.

Summary: _1_   (1 = Critical, 2 = Important, 3 = Cosmetic, 4 = Documentation, 5 = None)

Evaluator: Steven Humphreys   Date:3/25/96

Disposition:

Scope: _✓_ Current   _ New

Code: _✓_ Revise   _ Defer   _ No Change Required

Documentation: _ User's Guide   _ Tech. Desc.   _ No Documentation

Comments:
    Corrected

Date: 3/25/96

3.3 RADTRAD Acceptance Test Cases

3.3.1 Introduction

The RADTRAD acceptance test plan was developed cooperatively with the U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Division of Reactor Program Management; Sandia National Laboratories, Department of Accident Analysis and Consequence Assessment, and Pacific Northwest National Laboratory. The competing goals of validating real cases, validating ideal cases, and validating the RADTRAD code were merged through the generation of three types of acceptance cases. The first type validated the ideal cases by comparing RADTRAD solutions with analytic solutions. For this type of comparison, the quantitative acceptance criteria in the dose estimate for the environment was set at less than 1%. In the 4 cases of this type, RADTRAD exceeded the performance criteria. The second type validated many of RADTRAD's features while using reactor/control configurations typical of BWRs, PWRs, and advanced PWRs. For comparison purposes, an enhanced version of the HABIT code [St95] was run and the results compared. For these sets of cases, the quantitative acceptance criteria were typically in the 10-15% range for doses in the environment and activity in the control room. In the 25 cases of this type, RADTRAD greatly exceed the performance criteria by typically comparing within 1% for doses in the control room and in the environment. The third type of validation examined the new features incorporated into the RADTRAD code, such as analytic models for spray decontamination and deposition in rooms and pipes. In these cases, there are no comparative results; hence comparison was limited to other cases where either no deposition or user-specified removal rates were used. In these 7 cases the RADTRAD code met qualitative acceptance criteria by following correct trends. This section documents the input and output for the 32 acceptance cases as well as their comparisons with each other and calculated solutions from other techniques. These test cases were developed for the purpose of testing the code and were not intended to represent real licensing situations.

3.3.1.1 Acceptance Test Procedure

As noted above, the selection of suitable acceptance test cases was a cooperative process. In general, the plan was incremental, initially defining simplified test cases that could be verified against analytic solutions, then adding complexity (typically a control room) and comparing the results against the HABIT code analysis, adding more complexity (typically a fixed input radionuclide removal rate) and comparing results with the HABIT code again, and adding yet additional complexity in the form of a model of a removal mechanism and examining the trends. HABIT is a group of codes used to evaluate control room habitability issues that was developed by PNNL. It includes an activity transport code, TACT5, which has been in general use since 1988, as well as a control room dose evaluation code, CONHAB, that does both an atmospheric dispersion calculation and a dose calculation. The code uses explicit numerical techniques to solve the equations and link the codes together. PNNL supplied the HABIT results.

In a typical situation, for example, stepping from acceptance test case 2 to acceptance test case 3, the acceptance test team would discuss the input modifications necessary for the case and ensure the elimination of user-induced error. They would try to estimate the expected effect of the

modifications and perform the test cases. If the dose results did not compare to within a few percent, then the cases were recalculated with limited isotopes, either ^{131}I only or a mix of iodine, krypton, and cesium. This allowed a match of activity by volume and time for each isotope and for each chemical form (aerosol, organic, or elemental) and therefore provided a method to isolate the cause for discrepancies from expected results. Thus each case was brought into agreement with the analytic solution and with the HABIT results. After each set of cases was tested, the doses were then examined for case-to-case trends. In progressing through more complex cases, a difference in the air submersion calculation within the control room was determined to be more important than originally anticipated and corrective action was taken.

Table 3.3.1.1-1 is the original design for the acceptance plan. The sequence of acceptance tests is based on three reactors: a PWR, a BWR, and an advanced PWR. As the sequence steps from left to right, additional complexity is added. As the sequence steps from top to bottom, either a different reactor design is specified or the radionuclide release to the containment is changed. Of the 24 cases listed, only cases 17 and 18 are not reported here. These two cases were eliminated because it was concluded that they would not give significantly more information than other test cases due to the insignificant amount of pipe deposition. In addition to the resulting 22 cases, 10 perturbations were introduced to isolate particular effects, such as decay and daughtering, or a particular deposition mechanism.

The acceptance test plan was meant to assess:

- The source term models, that is, the radionuclide release fractions and timings, and the inventory, decay, and daughtering for both the TID-14844 and the NUREG-1465 models.

- The dose calculations due to cloudshine and inhalation in both the environment and in the control room.

- Nuclide transport due to forced convection in the environment.

- Pathway removal models and tables for pipes and filters.

- Compartment (containment, environment, control room) removal models and tables for sprays, recirculation filters, and natural deposition.

The rationale for the acceptance test cases for this part of the assessment of the RADTRAD code is:

- Cases 1-10 use a PWR design (block 1 of Table 3.3.1.1-1).

- Test case 1 was developed to verify that a puff release of ^{131}I would leak from the containment correctly and match the analytic solution.

- Test case 2 was developed to verify that a puff release of the entire TID source term (I, Xe, and Kr) would leak from the containment correctly and match the analytic solution.

- Test case 2a was developed to verify that a puff release of the entire TID source term would radioactively decay correctly.

- Test case 2b was developed to verify that a puff release of the entire TID source term would radioactively decay and daughter correctly.

- Test case 3 was developed to verify that a control room could be added to the calculation and give the same dose results in the environment as case 2, and to add the control room dose calculation.

- Test case 4 was developed to verify the effect of natural deposition in the containment using the TID source term. Many believed that the 50% deposition assumption was overly optimistic.

- Test case 5 was developed to see the effect of using Henry's natural deposition correlation with the TID source term.

- Test case 6 was developed to verify that a timed release of ^{131}I would leak from the containment correctly and match the analytic solution.

- Test case 7 was developed to verify that a timed release of the entire NUREG-1465 source term for PWRs would leak from the containment correctly and match the analytic solution.

- Test case 7a was developed to verify that a timed release of the entire NUREG-1465 source term for PWRs would radioactively decay correctly.

- Test case 7b was developed to verify that a timed release of the entire NUREG-1465 source term for BWRs would leak from the containment correctly.

- Test case 7c was developed to verify that a timed release of the entire NUREG-1465 source term for BWRs would radioactively decay correctly.

- Test case 7d was developed to verify that a timed release of the entire NUREG-1465 source term for PWRs would radioactively decay correctly for 10 hr before release.

- Test case 8 was developed to verify that a control room could be added to the calculation and give the same dose results in the environment as case 7, and to add the control room dose calculation.

- Test case 9 was developed to show the effect of natural deposition in the containment using the NUREG-1465 source term.

- Test case 10 was developed to see the effect of using the Powers model for natural deposition in the containment when using the NUREG-1465 source term.

- Test case 10a was developed to see the effect of using Henry's correlation for natural deposition in the containment when using the NUREG-1465 source term.

- Cases 11-18 use a BWR design (block 2 of Table 3.3.1.1-1)

- Test case 11 was developed to examine the BWR containment and a leak path that passed through the main steam isolation valve before going to the environment. The use of the TID ^{131}I isotope for a puff source made the calculation easier to analyze.

- Test case 12 was developed to verify that the addition of a control room would not change the environmental doses and to add the control room dose calculation. The use of the TID ^{131}I isotope for a puff source made the calculation easier to analyze.

- Test case 13 was developed to examine pipe deposition and to verify that the results of a more detailed model for pipe deposition could be implemented into RADTRAD. In this case the Cline model [Cl91] was chosen. The model calculated that the iodine that was released in both aerosol and elemental form was totally trapped within the pipe and condenser network; hence the RADTRAD code used large decontamination factors for these two release forms. The model also calculated that the organic iodine increased as the calculation proceeded. Thus the RADTRAD input was adjusted to yield the same results by increasing the organic fraction to the values needed to yield the final value (7.4% instead of 4%), and the pipe decontamination factor table for organics had larger values at the earlier times. The use of the TID ^{131}I isotope for a puff source made the calculation easier to analyze.

- Test case 13b was developed to verify that the NUREG-1465 timed (^{131}I) source release could also be used.

- Test case 14 was developed to show the effect of using the RADTRAD pipe deposition model with the TID (^{131}I) puff source term.

- Test case 14b was developed to show the effect of using the RADTRAD pipe deposition model with the NUREG-1465 (^{131}I) timed source term.

- Test case 15 was developed to examine the BWR containment and a leak path that passed through the emergency core cooling system and auxiliary building before exiting to the environment. The NUREG-1465 ^{131}I timed source term was used to make the results easier to analyze.

- Test case 16 was developed to verify that the addition of a control room would have no effect upon the environment doses and to add the control room dose calculation.

- Cases 19-24 use an advanced PWR design (block 3 of Table 3.3.1.1-1).

- Test case 19 was developed to examine an advanced PWR design. In this case containment mixing was modeled with multiple leaks to the environment. The use of the NUREG-1465 ^{131}I isotope for a timed source made the calculation easier to analyze.

- Test case 20 was developed to examine the use of the full NUREG-1465 source with the case 19 assumptions.

- Test case 21 was developed to verify that the addition of a control room would have no effect upon the environment doses and to add the control room dose calculation.

- Test case 22 was developed to examine the effect of natural deposition in the multi-zoned containment.

- Test case 23 was developed to examine the effect of a spray removal coefficient.

- Test case 24 was developed to examine the effect of a spray removal model.

- Test case 24a was developed to examine the effect of aerosol addition to the source term on the spray removal model.

3.3.1.2 Acceptance Test Results

Tables 3.3.1.2-1 through 3.3.1.2-5 give the results for the 32 acceptance test cases compared with the HABIT results. As shown, there is less than a 1% difference in the dose calculated by the two codes both for locations in the environment and in the control room. The tables also indicate that the isotopic masses were within the test limits for those HABIT runs where activity results were available.

Table 3.3.1.2-1 delineates the PWR cases. Cases 1 through 5 use the TID source term, and cases 6 through 10A use the NUREG-1465 source term. In general, stepping away from the first row in each section increases the calculated dose as more of the source term is included. In stepping from the second to the third row, the inclusion of the control room allows a new location for a dose calculation. Note that there is no effect on the environment dose results. Stepping from row three to four in each section, the user-specified natural deposition in the containment is added, causing the dose to go down as radionuclides are deposited within the containment. Note, however, that in progressing from case 3 to 4 the doses increase. This is because the TID source term release of 50% of the iodine inventory to the containment also assumes that 50% of the released iodine will be deposited on the surfaces. Because natural deposition was the focus of case 4, the entire 50% was left in the containment atmosphere. Stepping from row four to row five (or six) invokes the use of the model instead of the user-supplied deposition rate. In the comparison of cases 4 and 5, this led to an increase in dose due to the inappropriate use of the model. These results indicate the incompatibility of using the TID source term with the new correlations because the TID assumptions on iodine distribution cause logical disconnects. In the comparison of case 9 with both 10 and 10A, where the Powers model [Po95] and the Henry correlation [Fa84] were in use, the results indicate that both methods give answers similar to an assumed deposition rate of 15% per hour. This indicates that the methods could be used to estimate deposition rates when insufficient data were available to the user.

Table 3.3.1.2-2 delineates the BWR cases. For acceptance testing, all of these cases are limited to a release of ^{131}I from the reactor to the containment. The differences between the TID and the NUREG releases are in magnitude, chemical form, and timing. Cases 11 through 14 used the TID source term to examine the case of a main steam isolation valve (MSIV) leak to the environment. These cases are modeled as a containment leak to the condenser followed by a

pipe leak to the environment. Case 11 shows that the two codes gave similar leaks to the environment. Case 12 shows that the addition of a control room had no effect upon the environment dose results and that the dose to the control room was similar. Case 13 included the deposition specified by the Cline model [Cl91], which calculates total deposition of the dominant aerosol and elemental iodine forms due to the condenser's large surface area. Thus, the environmental dose is greatly reduced. However, the control room dose has increased; this is because the control filters also eliminate elemental and aerosol chemical forms. Thus, the significant component of the control room dose is the state of the organics. In the Cline model, elemental iodine is transformed into organic iodine and released; hence the organic iodine form increases in the environment and in the control room. Case 14 includes the effect of the Brockmann model for deposition of aerosols as well as the Cline correlation for organic and elemental deposition. Because the TID source term is dominated by the release of iodine in its elemental form, aerosol deposition differences were masked. As in the comparison between the Cline model and the base case, the state of the organic iodine is the controlling feature. Cases 13B and 14B were introduced to examine the effect of using the NUREG-1465 source term, where the aerosols make up 95% of the released iodine, on the Cline and Brockmann deposition models. A direct comparison between the TID and NUREG-1465 results is not reasonable because the TID assumption on iodine deposition in the containment makes the released quantities dramatically different. Note that case 14B still has lower doses than case 13B and the organic iodine is still controlling, thus indicating the importance of reevolution. Cases 15 and 16 examine an emergency core cooling system (ECCS) leak to an auxiliary building followed by a leak to the environment. As the table indicates, the codes calculated essentially the same answers for all these cases.

Table 3.3.1.2-3 delineates the advanced PWR cases. All of these cases use the source term of NUREG-1465. The advanced PWR required more compartments. Case 22 added a specified removal rate due to natural deposition within the containment, resulting in aerosol deposition and a reduction dose. Cases 23 and 24 examine containment sprays. Case 23 utilized a user-provided coefficient removal whereas case 24 invoked a spray model developed by Powers and Burson [Po93]. The results indicate that the spray model yields results similar to the user-provided removal rate. In case 24A, additional aerosol material was added to the release to the containment to determine the effect upon spray deposition; as the model suggests, there were negligible changes.

Table 3.3.1.2-4 delineates a series of cases used to examine radionuclide decay and daughtering. In these cases, the TID source, as shown in Section 1.4.3, was examined in cases 2, 2A, and 2B. The PWR NUREG-1465 source term (see Section 1.4.3) limited to the design basis accident assumptions was examined in cases 7 and 7A. The full BWR NUREG-1465 source term was examined in cases 7B and 7C. Both codes follow the anticipated trends, i.e., the inclusion of decay allows some of the released material to decay and be removed from the calculation and therefore reduce the total containment activity. Note in Table 3.3.1.2-4 that iodine-131 abundance has decreased, the xenon-135 has disappeared due to its short half-life, and the xenon-131 has also decreased. When daughtering is also included, the quantity of xenon-131 increases due to the decay and daughtering of the iodine-131. Cases 7 and 7A show the same effect due to the inclusion of isotopic decay for the PWR source term and cases 7B and 7C for the BWR source term. Case 7D assumes a 10-hr delay between the time the release starts and the time the

reactor was shut down (scrammed). It shows the effect of a decay before release and should be compared with case 7A. In all these cases, the comparison with HABIT with respect to dose and activity is within 1%.

Table 3.3.1.2-5 shows the results for the analytic comparison. The cases are simplistic releases from the containment to the atmosphere. The RADTRAD and HABIT codes give the same answer. In the first two cases where the TID source term is used, the first line contains the calculated results and the second the analytic solution. For cases 6 and 7 where the NUREG-1465 source term is used, the first line contains the calculated results for a design basis accident, i.e., only the first two releases of the NUREG-1465 scenario. This line should only be used to compare RADTRAD and HABIT. The following two lines give the calculated and analytic solution using the draft NUREG-1465 four-release severe accident scenario. As anticipated, the severe accident releases more than the design basis accident; hence the LPZ doses are higher (row 2 is larger than row 1). Note that the EAB time frame is only the first 2 hr and the time frame of the design basis accident is 1.8 hr; hence the EAB doses (the first four columns) are very similar.

3.3.2 Acceptance Case General Input

All acceptance test cases estimated air submersion and inhalation doses at offsite locations. Most acceptance test cases also estimated doses in the control room. All doses are estimated using Federal Guidance Reports 11 and 12 (FGR 11 and 12) dose conversion factors (DCFs) for the following organs and pseudoorgans:

- Gonads
- Breast
- Lungs
- Red bone marrow
- Bone surface
- Thyroid
- Skin
- Effective dose equivalent

Remainder

In addition, the following derived doses are calculated:

- Whole body (effective air submersion dose)
- Thyroid (thyroid chronic inhalation dose)
- TEDE (effective air submersion dose + effective committed effective dose equivalent)

All acceptance test cases specified the following standard breathing rates, as defined in NRC Regulatory Guides 1.3 and 1.4 for the EAB and LPZ. [Note: the table below indicates that from 0.0000 to 8.0000 hr the breathing rate would be 0.3470E-03 m^3/s; from 8.0000 h to 24.0000 hr, at would be 0.1750E-03 m^3/s; and from 24.0000 hr to the end of the test case (30 days), the breathing rate would be 0.2320E-03 m^3/s]:

0.0000 hr	0.3470E-03 (m^3/s)
8.0000 hr	0.1750E-03 (m^3/s)
24.0000 hr	0.2320E-03 (m^3/s)

All acceptance test cases specified the breathing rate as 0.3470E-03 m^3/s for the control room. All acceptance test cases use the following occupancy factors, as defined in Section 6.4 of the Murphy-Campe[Mu74] report for the control room operator:

0.0000 hr	1.0000
24.0000 hr	0.6000
96.0000 hr	0.4000

All acceptance test cases will end at 720.0000 hr (30 days).

Note: Throughout this page and the acceptance test cases, the numeric values given are presented in the same format in which they will appear on the RADTRAD user interface screens and printouts. The format should not be taken as an indicator of numeric precision or the number of available significant digits.

Table 3.3.1.1-1 Acceptance test plan

Reactor: PWR

Scenario & Source Term	A. ^{131}I Only	B. Full Source Term	C. Column B plus control room	D. Column C plus user-specified natural deposition	E. Column C plus natural deposition models
Containment leak TID-14844	Test Case 1	Test Case 2[1]	Test Case 3	Test Case 4	Test Case 5
Containment leak NUREG-1465/PWR	Test Case 6	Test Case 7[1]	Test Case 8	Test Case 9	Test Case 10

Reactor: BWR

Scenario & Source Term I131 only	A. ^{131}I Only	B. Full Source Term (not used)	C. Column A plus control room	D. Column C plus user-specified pipe deposition	E. Column C plus pipe deposition models
MSIV leak TID-14844	Test Case 11		Test Case 12	Test Case 13	Test Case 14
ECCS leak NUREG-1465/BWR	Test Case 15		Test Case 16	Test Case 17[2]	Test Case 18[2]

Reactor: Advanced PWR

Scenario & Source Term	A. ^{131}I Only	B. Full Source Term	C. Column B plus control room	D. Column C plus user-specified natural deposition	E. Column D plus user sprays, and spray model
NUREG-1465/PWR	Test Case 19	Test Case 20	Test Case 21	Test Case 22	Test Cases 23-24

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[1] These cases were also used to evaluate decay and daughtering capabilities

[2] Acceptance test cases 17 and 18 have been eliminated from the acceptance matrix.

Table 3.3.1.2-1 PWR--Control room and natural deposition tests

Test Case	CODE	Exclusion Area Boundary Doses (rem)		Low Population Zone Doses (rem)		Control Room Doses (rem)		Control Room Activity (curie)	
		Thyroid	TEDE	Thyroid	TEDE	Thyroid	TEDE	^{131}I	^{135}Xe
TID-14844									
1	RADTRAD	443	13.6	2992	91.9				
	HABIT	443	13.6	2992	91.9				
2	RADTRAD	652	28.7	4400	220				
	HABIT	652	28.7	4400	220				
3	RADTRAD	652	28.8	4400	220	2660	95.5	3.950E-03	0.75
	HABIT	653	28.8	4400	220	2650	95.1	4.000E-03	
4	RADTRAD	1130	47.5	809	66.9	4940	169	7.320E-03	0.75
	HABIT	1130	47.6	808	66.8	4920	168	7.420E-03	
5	RADTRAD	1300	54.1	8470	392	5300	181	7.870E-03	.75
NUREG-1465/PWR									
6	RADTRAD	354	10.9	4905	151				
	HABIT	354	10.8	4905	151				
7	RADTRAD	518	25.3	7200	382				
	HABIT	518	25.3	7200	382				
8	RADTRAD	518	25.3	7200	382	481	25.7	7.310E-04	0.15
	HABIT	518	25.3	7200	382	479	25.6		
9	RADTRAD	477	23.4	707	54.4	179	12.7	2.520E-04	0.15
	HABIT	477	23.4	707	54.3	178	12.6	2.550E-04	
10	RADTRAD	509	24.9	837	60.9	185.5	13	2.520E-04	0.15
10A	RADTRAD	474	23.2	690	53.6	179	12.7	2.520E-04	0.15

Table 3.3.1.2-2 BWR--Control room and pipe deposition tests

Test Case	CODE (^{131}I only)	Exclusion Area Boundary Doses (rem)		Low Population Zone Doses (rem)		Control Room Doses (rem)		Control Room Activity (curie)	
		Thyroid	TEDE	Thyroid	TEDE	Thyroid	TEDE	^{131}I	^{135}Xe
TID-14844									
11	RADTRAD	6.22	0.191	2054	63.1				
	HABIT	6.26	0.192	2050	63.1				
12	RADTRAD	6.22	0.191	2054	63.1	279	8.50	3.40E-03	
	HABIT	6.26	0.192	2050	63.1	277	8.44	3.40E-03	
13	RADTRAD	0.283	0.0087	147	4.52	376	11.5	4.92E-03	
	HABIT	0.277	0.0085	145	4.45	372	11.3	4.86E-03	
14	RADTRAD	0.118	0.003	39	1.2	97.6	3.0	1.2E-03	
NUREG-1465/BWR (^{131}I only)									
13B	RADTRAD	0.0175	5.30E-04	87.0	2.67	213	6.48	2.99E-03	
	HABIT	0.0151	4.60E-04	86.5	2.6	211	6.44		
14B	RADTRAD	0.0040	1.20E-04	4.59	0.141	4.66	0.142	5.72E-05	
15	RADTRAD	3.41	0.105	82.2	2.53				
	HABIT	3.41	0.104	82.2	2.53				
16	RADTRAD	3.41	0.105	82.2	2.53	44.8	1.37	1.54E-04	
	HABIT	3.41	0.105	82.2	2.53	44.2	1.35	1.56E-04	

Table 3.3.1.2-3 PWR--Natural deposition and sprays tests

Test Case	CODE	Exclusion Area Boundary Doses (rem)		Low Population Zone Doses (rem)		Control Room Doses (rem)		Control Room Activity Curie	
		Thyroid	TEDE	Thyroid	TEDE	Thyroid	TEDE	^{131}I	^{135}Xe
NUREG-1465/PWR									
19	RADTRAD	314	9.62	3485	107				
	HABIT	315	9.66	3480	107				
20	RADTRAD	459	22.7	5070	342				
	HABIT	460	22.7	5070	342				
21	RADTRAD	459	22.7	5070	342	662	59.4	1.44E-03	0.988
	HABIT	460	22.7	5070	342	669	59.7	1.51E-03	
22	RADTRAD	424	21.1	1850	179	439	50.0	9.42E-04	0.988
	HABIT	425	21.1	1840	179	436	49.7	9.73E-04	
23	RADTRAD	61.7	4.16	58.1	106	14.1	36.2	2.83E-05	0.988
	HABIT	61.7	4.16	58.1	106	14	36	2.92E-05	
24	RADTRAD	68.6	4.54	60.4	106	14.3	36.2	2.83E-05	0.988
24A	RADTRAD	68.6	4.54	60.4	106	14.3	36.2	2.83E-05	0.988

Table 3.3.1.2-4 PWR and BWR decay and daughtering tests

Test Case	Code	Exclusion Area Boundary Dose (rem)		Low Population Zone Dose (rem)		Containment Activity (Curie)		
		Thyroid	TEDE	Thyroid	TEDE	^{131}I	^{135}Xe	^{131}Xe
TID-14844								
1	RADTRAD	443	13.6	2992	91.9	1.140E+07		
	HABIT	443	13.6	2992	91.9	1.140E+07		
2	RADTRAD	652	28.7	4400	220	1.140E+07	9.37E+07	4.64E+05
	HABIT	652	28.8	4400	220	1.140E+07	9.37E+07	4.64E+05
2A	RADTRAD	640	26.4	1625	53.1	8.600E+05	0	8.07E+04
	HABIT	640	26.2	1610	52.6	8.600E+05	0	8.81E+04
2B	RADTRAD	640	26.4	1625	53.2	8.600E+05	0	1.07E+05
NUREG-1465/PWR						^{131}I	^{135}Xe	^{137}Cs
6	RADTRAD	354	10.9	4905	151	3.551E+07		
	HABIT	354	10.8	4905	151			
7	RADTRAD	518	25.3	7200	382	1.89E+07	1.88E+07	
	HABIT	518	25.3	7200	382			
7A	RADTRAD	507	23.6	2680	157	1.43E+06	0	1.07E+06
	HABIT	505	23.4	2660	156			
NUREG-1465/BWR								
7B	RADTRAD	378	20.2	5530	327	1.44E+07	2.40E+07	1.18E+06
	HABIT	378	20.2	5530	326			
7C	RADTRAD	370	18.9	2060	148	1.09E+06	0	1.18E+06
	HABIT	369	18.7	2040	147			
NUREG-1465/PWR								
7D	RADTRAD	446	19.6	2510	150	1.38E+06		
	HABIT	444	19.5	2500	150	1.37E+06		0

Table 3.3.1.2-5 Analytic solution tests

CASE		EXCLUSION AREA BOUNDARY				LOW POPULATION ZONE			
		Thyroid Dose		TEDE Dose		Thyroid Dose		TEDE Dose	
		RADTRAD	HABIT	RADTRAD	HABIT	RADTRAD	HABIT	RADTRAD	HABIT
1	TID ^{131}I								
	No Decay	443	444	13.57	13.59	2992	2988	91.9	91.8
	Analytic	443		13.57		2992		91.9	
2	TID Full Source								
	No Decay	652	652.7	28.7	28.8	4400	4397	220	220
	Analytic	652		28.7		4400		220	
6	PWR NUREG-1465 ^{131}I								
	No Decay	354	354	10.9	10.8	4905	4905	151	151
	Draft 1465 (4 releases)	356.6		10.9		9078		278.8	
	Analytic (4 releases)	356.7		10.9		9078		278.8	
7	NUREG-1465								
	No Decay	518	518	25.3	25.3	7200	7200	382	382
	Draft 1465 (4 releases)	522.5		25.7		14190		976.6	
	Analytic (4 releases)	522.5		25.7		14190		976.6	

3.3.3 Acceptance Test Case 1

Problem Description

PWR design (see Figure 1).

Instantaneous, modified TID-14844 (^{131}I only) release into containment.

Release begins at reactor shutdown.

No explicit calculation of removal mechanisms in the containment, but 50% of the released iodine is deposited in accordance with TID-14844.

Containment leak to the environment.

EAB and LPZ doses calculated.
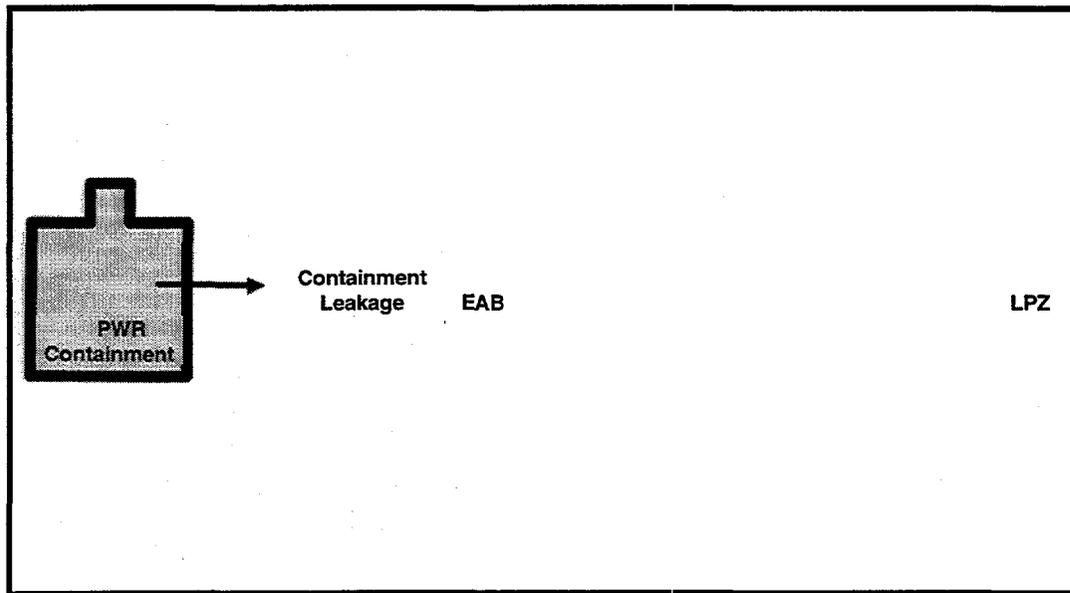
Figure 1. PWR Containment Leakage

Source Term

Release fractions and timing:	TID-14844, Table IV with modifications per NRC Regulatory Guides 1.3 and 1.4 (removes mixed fission products and details iodine fractions) and further modified as described below.
Start of release:	0.0000 hr
Iodine fractions:	Fraction of released iodine chemical form:

        Elemental: 0.9100
        Organic: 0.0400
        Aerosol: 0.0500

Inventory:	TID-14844 example normalized core inventory modified as follows:

        ^{131}I only

Reactor power:	1932 MWth

Plant Model

Containment volume:	0.1730E+07 ft^3
Environment	
Containment leakage:	Air leakage from: Containment to: Environment

Scenario Description

Containment leak rate: 0.1200%/day

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E−02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Success Criteria

All of the RADTRAD-calculated doses must equal the analytically derived doses within ± 0.1%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 1		RADTRAD	Analytic Solution
EAB	Thyroid (rem)	443	443
	TEDE (rem)	13.57	13.57
LPZ	Thyroid (rem)	2992	2992
	TEDE (rem)	91.9	91.9

3.3.4 Acceptance Test Case 2

Problem Description

PWR design (see Figure 1).
Instantaneous, modified TID-14844 release into containment.
Release begins at reactor shutdown.
No decay and no daughtering.
No explicit calculation of removal mechanisms in the containment, but 50% of the released iodine is deposited in accordance with TID-14844.
Containment leak to the environment.
EAB and LPZ doses calculated.

Source Term

Release fractions and timing:	TID-14844, Table IV with modifications per NRC Regulatory Guides 1.3 and 1.4.
Start of release:	0.0000 hr
Iodine fractions:	Fraction of released iodine chemical form:

Elemental:	0.9100
Organic:	0.0400
Aerosol:	0.0500

Inventory:	TID-14844 example normalized core inventory
Reactor power:	1932 MWth

Plant Model

Containment volume:	$0.1730E+07 \ ft^3$

Environment

Containment leakage:	Air leakage	from: Containment	to: Environment

Scenario Description

Containment leak rate:	0.1200%/day

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Success Criteria

All of the RADTRAD-calculated doses must equal the analytically derived doses within ± 0.1%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 2		RADTRAD	Analytic Solution
EAB	Thyroid (rem)	652.	652.
	TEDE (rem)	28.7	28.7
LPZ	Thyroid (rem)	4400	4400
	TEDE (rem)	220	220

3.3.5 Acceptance Test Case 2A

Problem Description
PWR design (see Figure 1).
Instantaneous, modified TID-14844 release into containment.
Decay without daughtering included.
Release begins at reactor shutdown.
No explicit calculation of removal mechanisms in the containment, but 50% of the released iodine is
    deposited in accordance with TID-14844.
Containment leak to the environment.
EAB and LPZ doses calculated.

Source Term
Release fractions and timing: TID-14844, Table IV with modifications per NRC regulatory guides 1.3 and 1.4.

Start of release: 0.0000 hr

Iodine fractions: Fraction of released iodine chemical form:

Elemental:	0.9100
Organic:	0.0400
Aerosol:	0.0500

Inventory: TID-14844 example normalized core inventory

Reactor power: 1932 MWth

Plant Model
Containment volume: $0.1730E+07$ ft^3

Environment

Containment leakage: Air leakage   from: Containment   to: Environment

Scenario Description
Containment leak rate: 0.1200%/day

Dose Parameters
EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Success Criteria
All of the RADTRAD-calculated doses must equal the doses calculated by HABIT within ± 5%.

Acceptance Criteria
All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 2A		RADTRAD	HABIT
EAB	Thyroid (rem)	640	640
	TEDE (rem)	26.4	26.17
LPZ	Thyroid (rem)	1625	1610
	TEDE (rem)	53.1	52.6

3.3.6 Acceptance Test Case 2B

Problem Description

PWR design (see Figure 1).

Instantaneous, modified TID-14844 release into containment.

Decay and daughtering included.

Release begins at reactor shutdown.

No explicit calculation of removal mechanisms in the containment, but 50% of the released iodine is deposited in accordance with TID-14844.

Containment leak to the environment.

EAB and LPZ doses calculated.

Source Term

Release fractions and timing:	TID-14844, Table IV with modifications per NRC Regulatory Guides 1.3 and 1.4.
Start of release:	0.0000 hr
Iodine fractions:	Fraction of released iodine chemical form:

Elemental:	0.9100
Organic:	0.0400
Aerosol:	0.0500

Inventory:	TID-14844 example normalized core inventory
Reactor power:	1932 MWth

Plant Model

Containment volume: $0.1730E+07$ ft^3

Environment

Containment leakage: Air leakage   from: Containment   to: Environment

Scenario Description

Containment leak rate: 0.1200%/day

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Success Criteria

All of the RADTRAD-calculated doses must equal the doses calculated by HABIT within ± 5%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 2B		RADTRAD	RADTRAD 2A
EAB	Thyroid (rem)	640	640
	TEDE (rem)	26.4	26.4
LPZ	Thyroid (rem)	1625	1625
	TEDE (rem)	53.2	53.1

Table 3.3.1.2-4 shows some of the isotopic changes for these two cases.

3.3.7 Acceptance Test Case 3

Problem Description

PWR design (see Figure 1).

Instantaneous, modified TID-14844 release into the containment.

Release begins at reactor shutdown.

No explicit calculation of removal mechanisms in the containment, but 50% of the released iodine is deposited in accordance with NRC Regulatory Guide 1.4.

Containment leak to the environment.

Control room air filtration system (see Figure 2).

EAB, LPZ, and CR doses calculated.

Figure 2. PWR Control Room Detail

Source Term

Release fractions and timing: TID-14844, Table IV with modifications per NRC Regulatory Guide 1.4.

Start of release: 0.0000 hr

Iodine fractions: Fraction of released iodine chemical form:

Organic	0.0400
Elemental:	0.9100
Aerosol:	0.0500

Inventory: TID-14844 example normalized core inventory

Reactor power: 1932 MWth

Plant Model

Containment volume: $0.1730E+07$ ft^3

Control room volume: $0.4238E+05$ ft^3

Control room removal: Recirculating filter # 2.

Environment

Containment leakage:	Air leakage	from: Containment	to: Environment
Filter #1:	Filtered pathway	from: Environment	to: Control room
Filter #2:	Recirculation filter	from: Control room	to: Control room
CR exhaust:	Air leakage	from: Control room	to: Environment
CR unfiltered inflow:	Air leakage	from: Environment	to: Control room

Scenario Description

Containment leak rate:	0.1200%/day
Filter #1 flow rate:	3000 cfm

Filter #1 efficiencies:

Elemental iodine	99.0000%
Organic iodine	00.0000%
Aerosols	99.0000%

Filter #2 flow rate: 10000 cfm

Filter #2 Efficiencies:

Elemental iodine	90.0000%
Organic iodine	00.0000%
Aerosols	90.0000%

CR exhaust:	3010 cfm
CR unfiltered inflow:	10 cfm

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Filter #1 X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.2200E-02
2.0000	0.1500E-02
8.0000	0.1300E-02
24.0000	0.8400E-03
96.0000	0.4800E-03

Success Criteria

All of the RADTRAD-calculated EAB, LPZ, and CR doses must equal the doses calculated by HABIT within ± 5.0%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 3		RADTRAD	HABIT
EAB	Thyroid (rem)	652	653
	TEDE (rem)	28.8	28.8
LPZ	Thyroid (rem)	4400	4400
	TEDE (rem)	220	220
CR	Thyroid (rem)	2660	2650
	TEDE (rem)	95.5	95.1

3.3.8 Acceptance Test Case 4

Problem Description

PWR design (see Figure 1).
Instantaneous, TID-14844 release into the containment.
Release begins at reactor shutdown.
In-containment aerosol removal via natural deposition with user-defined removal rates.
Containment leak to the environment.
Control room air filtration system (see Figure 2).
EAB, LPZ, and CR doses calculated.

Source Term

Release fractions and timing: TID-14844, Table IV with aerosol-only modifications per NRC Regulatory Guide 1.4.

Start of release: 0.0000 hr

Iodine fractions: Fraction of released iodine chemical form:

Elemental:	0.9100
Organic:	0.0400
Aerosol:	0.0500

Inventory: TID-14844 example normalized core inventory

Reactor power: 1932 MWth

Plant Model

Containment volume: $0.1730E+07$ ft^3

Containment removal: Aerosol removal via natural deposition with user-defined removal rates.

Control room volume: $0.4238E+05$ ft^3

Environment

Containment leakage:	Air leakage	from: Containment	to: Environment
Filter #1:	Filtered pathway	from: Environment	to: Control room
Filter #2:	Recirculation filter	from: Control room	to: Control room
CR exhaust:	Air leakage	from: Control room	to: Environment
CR unfiltered inflow:	Air leakage	from: Environment	to: Control room

Scenario Description

Containment leak rate: 0.1200%/day

Natural deposition
   aerosol removal rate: 0.15 hr^{-1}
   elemental removal rate: 0.15 hr^{-1}

Filter #1 flow rate: 3000 cfm

Filter #1 efficiencies:

Elemental iodine	99.0000%
Organic iodine	00.0000%
Aerosols	99.0000%

Filter #2 flow rate: 10000 cfm

Filter #2 efficiencies:

Elemental iodine	90.0000%
Organic iodine	00.0000%
Aerosols	90.0000%

CR unfiltered inflow:	10 cfm	
CR exhaust:	3010 cfm	

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

CR air intake X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.2200E-02
2.0000	0.1500E-02
8.0000	0.1300E-02
24.0000	0.8400E-03
96.0000	0.4800E-03

Success Criteria

All of the RADTRAD-calculated EAB, LPZ, and CR doses must equal the doses calculated by HABIT within ± 5.0%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 4		RADTRAD	HABIT
EAB	Thyroid (rem)	1130	1130
	TEDE (rem)	47.5	47.6
LPZ	Thyroid (rem)	808	808
	TEDE	66.9	66.8
CR	Thyroid (rem)	4940	4940
	TEDE	169	168

3.3.9 Acceptance Test Case 5

Problem Description

PWR design (see Figure 1).

Instantaneous, TID-14844 release into the containment.

Release begins at reactor shutdown.

In-containment aerosol removal via natural deposition using Henry's correlation [Fa84]. Because this model deposits only aerosols and the TID releases elementals, the problem is duplicated as case 10A.

Containment leak to the environment.

Control room air filtration system (see Figure 2).

EAB, LPZ, and CR doses calculated.

Source Term

Release fractions and timing:	TID-14844, Table IV with aerosol-only modifications per NRC Regulatory Guide 1.4.
Start of release:	0.0000 hr
Iodine fractions:	Fraction of released iodine chemical form:

	Elemental:	0.9100
	Organic:	0.0400
	Aerosol:	0.0500

Inventory:	TID-14844 example normalized core inventory
Reactor power:	1932 MWth

Plant Model

Containment volume:	$0.1730E+07$ ft^3
Containment removal:	Aerosol removal determined by Henry's correlation for natural deposition.
Control room volume:	$0.4238E+05$ ft^3
Environment	

Containment leakage:	Air leakage	from: Containment	to: Environment
Filter #1:	Filtered pathway	from: Environment	to: Control room
Filter #2:	Recirculation filter	from: Control room	to: Control room
CR exhaust:	Air leakage	from: Control room	to: Environment
CR unfiltered inflow:	Air leakage	from: Environment	to: Control room

Scenario Description

Containment leak rate:	0.1200%/day
Henry's natural deposition parameters:	16.4 ft (16.4 ft = reference value)
	Particle theoretical density = 1.0 g/cm^3 (2.27g/cm^3 = reference value)
Filter #1 flow rate:	3000 cfm

Filter #1 efficiencies:	Elemental iodine	99.0000%
	Organic iodine	00.0000%
	Aerosols	99.0000%

Filter #2 flow rate:	10,000 cfm

Filter #2 efficiencies:	Elemental iodine	90.0000%
	Organic iodine	00.0000%
	Aerosols	90.0000%

CR unfiltered inflow: 10 cfm

CR exhaust: 3010 cfm

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

CR air intake X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.2200E-02
2.0000	0.1500E-02
8.0000	0.1300E-02
24.0000	0.8400E-03
96.0000	0.4800E-03

Success Criteria

Deposition rate should be found to be reasonable.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC. If the success criteria are not met in the RADTRAD version under test, the software will still be acceptable to the NRC. SNL will be responsible for determining the cause of the failure and correction will be expected before project closeout.

Results

Test Case 5		RADTRAD	RADTRAD CASE 4
EAB	Thyroid (rem)	1300	1130
	TEDE (rem)	54.1	47.5
LPZ	Thyroid (rem)	8470	808
	TEDE (rem)	392	66.9
CR	Thyroid (rem)	5300	4940
	TEDE (rem)	181	169

These calculations indicate less iodine deposition with the model, resulting in higher doses in the environment and control room. This case is an example of the code being used incorrectly.

3.3.10 Acceptance Test Case 6

Problem Description

PWR design (see Figure 1).
Modified NUREG-1465 PWR (^{131}I only) release into containment.
Release begins at reactor shutdown.
No removal mechanisms.
Containment leak to the environment.
EAB and LPZ doses calculated.

Source Term

Release fractions and timing: NUREG-1465, Tables 3.12 and 3.13 with modifications as described below.

Start of release: 0.0000 hr

Iodine fractions: 1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory: Normalized MACCS sample 3412 MWth PWR core inventory modified as follows:

[131]I only

Reactor power: 1932 MWth

Plant Model

Containment volume: $0.1730E+07 \ ft^3$

Environment

Containment leakage: Air leakage   from: Containment   to: Environment

Scenario Description

Containment leak rate: 0.1200%/day

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Success Criteria

All of the RADTRAD-calculated doses must equal the analytically derived doses within ± 0.1%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 6		RADTRAD	HABIT
EAB	Thyroid (rem)	354	354
	TEDE (rem)	10.9	10.8
LPZ	Thyroid (rem)	4907	4905
	TEDE (rem)	150.7	151

In Table 3.3.1.2-5 this case is also compared with HABIT with decay but no in-growth included. In addition, a case using the severe accident iodine release from NUREG 1465 is compared with the analytic solution in that table.

3.3.11 Acceptance Test Case 7

Problem Description

PWR design (see Figure 1).
NUREG-1465 PWR release into containment.
No decay and no daughtering.
Release begins at reactor shutdown.
No removal mechanisms.
Containment leak to the environment.
EAB and LPZ doses calculated.

Source Term

Release fractions and timing: NUREG-1465, Tables 3.12 and 3.13.

Start of release: 0.0000 hr

Iodine fractions: 1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory: Normalized MACCS sample 3412 MWth PWR core inventory

Reactor power: 1932 MWth

Plant Model

Containment volume: $0.1730E+07 \text{ ft}^3$

Environment

Containment leakage: Air leakage   from: Containment   to: Environment

Scenario Description

Containment leak rate: 0.1200%/day

Dose Parameters

EAB X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.1000E-02
	2.0000	0.0000E+00

LPZ X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.1350E-03
	8.0000	0.1000E-03
	24.0000	0.5400E-04
	96.0000	0.2200E-04

Success Criteria

All of the RADTRAD-calculated doses must equal the analytically derived doses within ± 0.1%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 7		RADTRAD	HABIT
EAB	Thyroid (rem)	518	518
	TEDE (rem)	25.3	25.3
LPZ	Thyroid (rem)	7200	7200
	TEDE (rem)	382	382

In Table 3.3.1.2-5 this case is also compared with HABIT with decay but no in-growth included. In addition, a case using the severe accident iodine release from NUREG 1465 is compared with the analytic solution in that table.

3.3.12 Acceptance Test Case 7A

Problem Description

    PWR design (see Figure 1).
    NUREG-1465 PWR release into containment.
    Decay but no daughtering.
    Release begins at reactor shutdown.
    No removal mechanisms.
    Containment leak to the environment.
    EAB and LPZ doses calculated.

Source Term

Release fractions and timing:	NUREG-1465, Tables 3.12 and 3.13.
Start of release:	0.0000 hr
Iodine fractions:	1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory:	Normalized MACCS sample 3412 MWth PWR core inventory
Reactor power:	1932 MWth

Plant Model

Containment volume:	$0.1730E+07 \ ft^3$

Environment

Containment leakage:	Air leakage from: Containment to: Environment

Scenario Description

Containment leak rate:	0.1200%/day

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Success Criteria

    All of the RADTRAD-calculated EAB and LPZ doses must equal the doses calculated by HABIT within ± 5.0%.

Acceptance Criteria

    All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 7A		RADTRAD	HABIT
EAB	Thyroid (rem)	507	505
	TEDE (rem)	23.6	23.4
LPZ	Thyroid (rem)	2680	2660
	TEDE (rem)	157	156

3.3.13 Acceptance Test Case 7B

Problem Description
PWR design (see Figure 1).
NUREG-1465 BWR release into containment.
No decay and no daughtering.
Release begins at reactor shutdown.
No removal mechanisms.
Containment leak to the environment.
EAB and LPZ doses calculated.

Source Term
Release fractions and timing: NUREG-1465, Tables 3.12 and 3.13.

Start of release: 0.0000 hr

Iodine fractions: 1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory: Normalized MACCS sample 3412 MWth BWR core inventory

Reactor power: 1932 MWth

Plant Model
Containment volume: $0.1730E+07$ ft^3

Environment

Containment leakage: Air leakage   from: Containment   to: Environment

Scenario Description
Containment leak rate: 0.1200%/day

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Success Criteria
All of the RADTRAD-calculated EAB, LPZ, and CR doses must equal the doses calculated by HABIT within ± 5.0%.

Acceptance Criteria
All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 7B		RADTRAD	HABIT
EAB	Thyroid (rem)	378	378
	TEDE (rem)	20.2	20.2
LPZ	Thyroid (rem)	5530	5530
	TEDE (rem)	327	326

3.3.14 Acceptance Test Case 7C

Problem Description
PWR design (see Figure 1).
NUREG-1465 BWR release into containment.
Decay but no daughtering.
Release begins at reactor shutdown.
No removal mechanisms.
Containment leak to the environment.
EAB and LPZ doses calculated.

Source Term
Release fractions and timing: NUREG-1465, Tables 3.12 and 3.13.

Start of release: 0.0000 hr

Iodine fractions: 1.0000

Fraction of released iodine chemical form:

   Elemental: 0.0485
   Organic: 0.0015
   Aerosol: 0.9500

Inventory: Normalized MACCS sample 3412 MWth BWR core inventory

Reactor power: 1932 MWth

Plant Model
Containment volume: $0.1730E+07 \ ft^3$

Environment

Containment leakage: Air leakage   from: Containment   to: Environment

Scenario Description
Containment leak rate: 0.1200%/day

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Success Criteria
All of the RADTRAD-calculated EAB, LPZ, and CR doses must equal the doses calculated by HABIT within
± 5.0%.

Acceptance Criteria
All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the
NRC.

Results

Test Case 7C		RADTRAD	HABIT
EAB	Thyroid (rem)	370	369
	TEDE (rem)	18.9	18.7
LPZ	Thyroid (rem)	2060	2040
	TEDE (rem)	148	147

3.3.15 Acceptance Test Case 7D

Problem Description

PWR design (see Figure 1).
NUREG-1465 PWR release into containment.
Decay and no daughtering.
Release begins 10 hr after reactor shutdown.
No removal mechanisms.
Containment leak to the environment.
EAB and LPZ doses calculated.

Source Term

Release fractions and timing: NUREG-1465, Tables 3.12 and 3.13.

Start of release: 10.0000 hr

Iodine fractions: 1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory: Normalized MACCS sample 3412 MWth PWR core inventory

Reactor power: 1932 MWth

Plant Model

Containment volume: $0.1730E+07$ ft^3

Environment

Containment leakage: Air leakage   from: Containment   to: Environment

Scenario Description

Containment leak rate: 0.1200%/day

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Success Criteria

All of the RADTRAD-calculated EAB, LPZ, and CR doses must equal the doses calculated by HABIT within ± 5.0%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

RADTRAD		Case 7	Case 7D	Case 7A	HABIT 7D
EAB	Thyroid (rem)	518	446	507	445
	TEDE (rem)	25.3	19.6	23.4	19.5
LPZ	Thyroid (rem)	7200	2510	2680	2500
	TEDE (rem)	382	150	157	150

The cases shown above are all PWRs, Note that without decay the doses are high (case 7); when decay is added, the doses fall significantly (case 7A). When the decay goes on for 10 hr before the source term is released, the doses should be even lower, although not substantially. The comparison with the HABIT code is shown to indicate the relative accuracy.

3.3.16 Acceptance Test Case 8

Problem Description
PWR design (see Figure 1).
NUREG-1465 PWR release into containment.
Release begins at reactor shutdown.
No removal mechanisms.
Containment leak to the environment.
Control room air filtration system (see Figure 2).
EAB, LPZ, and CR doses calculated.

Source Term

Release fractions and timing:	NUREG-1465, Tables 3.12 and 3.13.

Start of release: 0.0000 hr

Iodine fractions: 1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory: Normalized MACCS sample 3412 MWth PWR core inventory.

Reactor power: 1932 MWth

Plant Model

Containment volume: $0.1730E+07 \text{ ft}^3$

Control room volume: $0.4238E+05 \text{ ft}^3$

Control room removal: Recirculating filter # 2

Environment

Containment leakage:	Air leakage	from: Containment	to: Environment
Filter #1:	Filtered pathway	from: Environment	to: Control room
Filter #2:	Recirculation filter	from: Control room	to: Control room
CR exhaust:	Air leakage	from: Control room	to: Environment
CR unfiltered inflow:	Air leakage	from: Environment	to: Control room

Scenario Description

Containment leak rate: 0.12%/day

Filter #1 flow rate: 3000 cfm

Filter #1 efficiencies:	Elemental iodine	99.0000%
	Organic iodine	00.0000%
	Aerosols	99.0000%

Filter #2 flow rate: 10000 cfm

Filter #2 efficiencies:	Elemental iodine	90.0000%
	Organic iodine	00.0000%
	Aerosols	90.0000%

CR unfiltered inflow: 10 cfm

CR exhaust: 3010 cfm

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Filter #1 X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.2200E-02
2.0000	0.1500E-02
8.0000	0.1300E-02
24.0000	0.8400E-03
96.0000	0.4800E-03

Success Criteria

All of the RADTRAD-calculated EAB, LPZ, and CR doses must equal the doses calculated by HABIT within ± 5.0%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 8		RADTRAD	HABIT
EAB	Thyroid (rem)	518	518
	TEDE (rem)	25.3	25.3
LPZ	Thyroid (rem)	7200	7200
	TEDE (rem)	382	382
CR	Thyroid (rem)	481	479
	TEDE (rem)	25.7	25.6

3.3.17 Acceptance Test Case 9

Problem Description

PWR design (see Figure 1).
NUREG-1465 PWR release into containment.
Release begins at reactor shutdown.
In-containment aerosol removal via natural deposition with user-defined removal rates.
Containment leak to the environment.
Control room air filtration system (see Figure 2).
EAB, LPZ, and CR doses calculated.

Source Term

Release fractions and timing:	NUREG-1465, Tables 3.12 and 3.13.
Start of release:	0.0000 hr
Iodine fractions:	1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory:	Normalized MACCS sample 3412 MWth PWR core inventory
Reactor power:	1932 MWth

Plant Model

Containment volume:	$0.1730E+07 \ ft^3$
Containment removal:	Aerosol removal determined by user-defined rates for natural deposition.
Control room volume:	$0.4238E+05 \ ft^3$
Control room removal:	Recirculating filter # 2

Environment

Containment leakage:	Air leakage	from: Containment	to: Environment
Filter #1:	Filtered pathway	from: Environment	to: Control room
Filter #2:	Recirculation filter	from: Control room	to: Control room
CR exhaust:	Air leakage	from: Control room	to: Environment
CR unfiltered inflow:	Air leakage	from: Environment	to: Control Room

Scenario Description

Containment leak rate:	0.1200%/day
Natural deposition aerosol removal rate:	$0.15 \ hr^{-1}$
Filter #1 flow rate:	3000 cfm

Filter #1 efficiencies:

Elemental iodine	99.0000%
Organic iodine	00.0000%
Aerosols	99.0000%

Filter #2 flow rate:	10000 cfm

Filter #2 efficiencies:	Elemental iodine	90.0000%	
	Organic iodine	00.0000%	
	Aerosols	90.0000%	

CR unfiltered inflow: 10 cfm

CR exhaust: 3010 cfm

Dose Parameters

EAB X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.1000E-02
	2.0000	0.0000E+00

LPZ X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.1350E-03
	8.0000	0.1000E-03
	24.0000	0.5400E-04
	96.0000	0.2200E-04

Filter #1 X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.2200E-02
	2.0000	0.1500E-02
	8.0000	0.1300E-02
	24.0000	0.8400E-03
	96.0000	0.4800E-03

Success Criteria

All of the RADTRAD-calculated EAB, LPZ, and CR doses must equal the doses calculated by HABIT within ± 5.0%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 9		RADTRAD	HABIT
EAB	Thyroid (rem)	477	477
	TEDE (rem)	23.4	23.4
LPZ	Thyroid (rem)	707	707
	TEDE (rem)	54.4	54.3
CR	Thyroid (rem)	179	178
	TEDE (rem)	12.7	12.6

3.3.18 Acceptance Test Case 10

Problem Description
PWR design (see Figure 1).
NUREG-1465 PWR release into containment.
Release begins at reactor shutdown.
In-containment aerosol removal via natural deposition using Powers model [Po95].
Containment leak to the environment.
Control room air filtration system (see Figure 2).
EAB, LPZ, and CR doses calculated.

Source Term

Release fractions and timing:	NUREG-1465, Tables 3.12 and 3.13.
Start of release:	0.0000 h

Iodine fractions:

1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory:	Normalized MACCS sample 3412 MWth PWR core inventory
Reactor power:	1932 MWth

Plant Model

Containment volume:	0.1730E+07 ft^3
Containment removal:	Aerosol removal determined by Powers model for natural deposition.
Control room volume:	0.4238E+05 ft^3
Control room removal:	Recirculating filter # 2
Environment	

Containment leakage:	Air leakage	from: Containment	to: Environment
Filter #1:	Filtered pathway	from: Environment	to: Control room
Filter #2:	Recirculation filter	from: Control room	to: Control room
CR exhaust:	Air leakage	from: Control room	to: Environment
CR unfiltered inflow:	Air leakage	from: Environment	to: Control room

Scenario Description

Containment leak rate:	0.1200%/day
Powers natural deposition model parameters:	Reactor type = PWR design basis accident
	Best-estimate solution
Filter #1 flow rate:	3000 cfm

Filter #1 efficiencies:

Elemental iodine	99.0000%
Organic iodine	00.0000%
Aerosols	99.0000%

Filter #2 flow rate:	10,000 cfm

Filter #2 efficiencies:	Elemental iodine	90.0000%
	Organic iodine	00.0000%
	Aerosols	90.0000%

CR unfiltered inflow: 10 cfm

CR exhaust: 3010 cfm

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Filter #1 X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.2200E-02
2.0000	0.1500E-02
8.0000	0.1300E-02
24.0000	0.8400E-03
96.0000	0.4800E-03

Success Criteria

Deposition rate should be found to be reasonable.

Acceptance Criteria

If the success criteria not met in the RADTRAD version under test, the software will be still be acceptable to the NRC. However, SNL will be responsible for determining the cause of the failure and correction will be expected before project closeout.

Results

Test Case 10		RADTRAD	RADTRAD CASE 9
EAB	Thyroid (rem)	504	477
	TEDE (rem)	24.7	23.4
LPZ	Thyroid (rem)	781	707
	TEDE (rem)	58	54.4
CR	Thyroid (rem)	183	179
	TEDE (rem)	12.9	12.7

The results indicate more early aerosol deposition with the Powers natural deposition model, resulting in lower doses to the environment.

3.3.19 Acceptance Test Case 10A

Problem Description

PWR design (see Figure 1).

NUREG-1465 PWR release into containment.

Release begins at reactor shutdown.

In-containment aerosol removal via natural deposition using Henry's correlation [Fa84].

Containment leak to the environment.

Control room air filtration system (see Figure 2).

EAB, LPZ, and CR doses calculated.

Source Term

Release fractions and timing: NUREG-1465, Tables 3.12 and 3.13.

Start of release: 0.0000 hr

Iodine fractions: 1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory: Normalized MACCS sample 3412 MWth PWR core inventory

Reactor power: 1932 MWth

Plant Model

Containment volume: $0.1730E+07 \text{ ft}^3$

Containment removal: Aerosol removal determined by for Henry's correlation for natural deposition.

Control room volume: $0.4238E+05 \text{ ft}^3$

Control room removal: Recirculating filter # 2.

Environment

Containment leakage:	Air leakage	from: Containment	to: Environment
Filter #1:	Filtered pathway	from: Environment	to: Control room
Filter #2:	Recirculation filter	from: Control room	to: Control room
CR exhaust:	Air leakage	from: Control room	to: Environment
CR unfiltered inflow:	Air leakage	from: Environment	to: Control Room

Scenario Description

Containment leak rate: 0.1200%/day

Henry's natural deposition parameters: 16.4 ft (16.4 ft = reference value)

Particle theoretical density = 1.0 g/cm^3 (2.27g/cm^3 = reference value)

Filter #1 flow rate: 3000 cfm

Filter #1 efficiencies:

Elemental iodine	99.0000%
Organic iodine	00.0000%
Aerosols	99.0000%

Filter #2 flow rate: 10000 cfm

Filter #2 efficiencies:	Elemental iodine	90.0000%
	Organic iodine	00.0000%
	Aerosols	90.0000%

CR unfiltered inflow: 10 cfm

CR exhaust: 3010 cfm

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Filter #1 X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.2200E-02
2.0000	0.1500E-02
8.0000	0.1300E-02
24.0000	0.8400E-03
96.0000	0.4800E-03

Success Criteria

Deposition rate should be found to be reasonable.

Acceptance Criteria

If the success criteria are not met in the RADTRAD version under test, the software will be still be acceptable to the NRC. However, SNL will be responsible for determining the cause of the failure and correction will be expected before project closeout.

Results

Test Case 10A		RADTRAD Case 10A	RADTRAD Case 9	RADTRAD Case 10
EAB	Thyroid (rem)	474	477	504
	TEDE (rem)	23.2	23.4	24.7
LPZ	Thyroid (rem)	690	707	781
	TEDE (rem)	53.6	54.4	58
CR	Thyroid (rem)	179	179	183
	TEDE (rem)	12.7	12.7	12.9

The results indicate less aerosol deposition overall with same residual aerosol at 30 days, resulting in somewhat higher doses for Henry's correlation compared with the Powers model (case 10) and the constant rate model (case 9).

3.3.20 Acceptance Test Case 11

Problem Description

BWR-Mark II containment (see Figure 3).

Instantaneous, modified TID-14844 (^{131}I only) release into containment.

Release begins at reactor shutdown.

No explicit calculation of removal mechanisms in the containment, but 50% of the released iodine is deposited in accordance with NRC Regulatory Guide 1.3.

Containment leak into condenser via main steam line, condenser leak to the environment.

EAB and LPZ doses calculated.
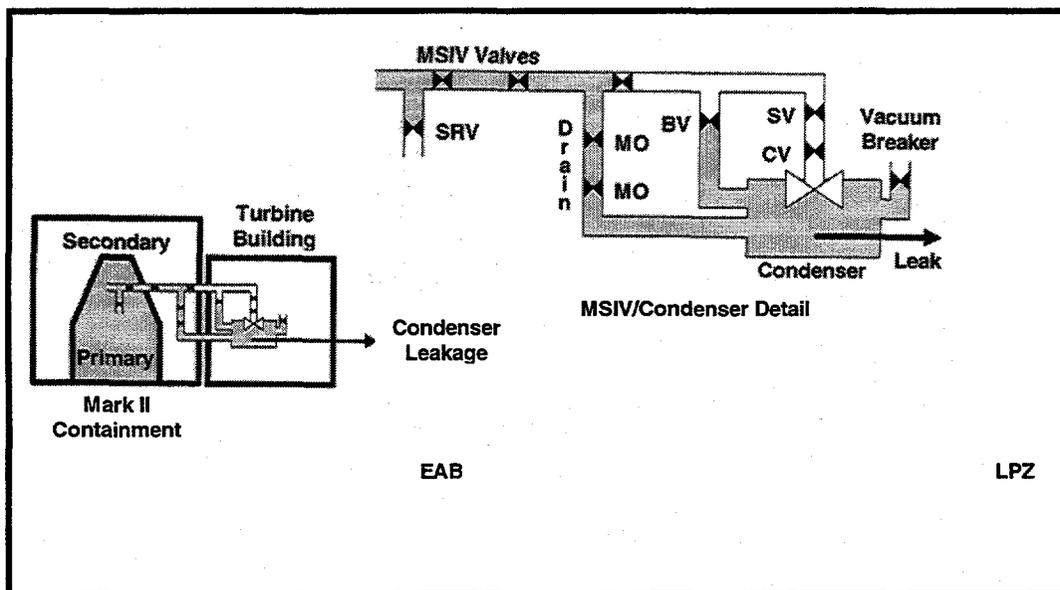
Figure 3. BWR-Mark II Containment MSIV/Condenser Leak

Source Term

Release fractions and timing: TID-14844, Table IV with modifications per NRC Regulatory Guide 1.3 and further modified as described below.

Start of release: 0.0000 hr

Iodine fractions: 1.0000

Fraction of released iodine chemical form:

Elemental:	0.9100
Organic:	0.0400
Aerosol:	0.0500

Inventory: TID-14844 example normalized core inventory modified as follows:
^{131}I only

Reactor power: 3441 MWth

Plant Model

Containment volume: 0.389E+06 ft^3

Effective condenser volume: 0.986E+05 ft^3

Environment

| Containment leakage: | Piping | from: Containment | to: Condenser |
| Condenser leakage: | Air leakage | from: Condenser | to: Environment |

Scenario Description

Containment leak rate: 1.85%/day

Condenser leak rate: 0.7666 cfm

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1100E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.5200E-04
8.0000	0.3600E-04
24.0000	0.1600E-04
96.0000	0.5300E-05

Success Criteria

All of the RADTRAD-calculated EAB and LPZ doses must equal the doses calculated by HABIT within ± 5.0%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 11		RADTRAD	HABIT
EAB	Thyroid (rem)	6.22	6.26
	TEDE (rem)	0.191	0.192
LPZ	Thyroid (rem)	2054	2050
	TEDE (rem)	63.1	63.1

3.3.21 Acceptance Test Case 12

Problem Description

BWR-Mark II containment (see Figure 3).

Instantaneous, modified TID-14844 (^{131}I only) release into containment.

Release begins at reactor shutdown.

No explicit calculation of removal mechanisms in the containment, but 50% of the released iodine is deposited in accordance with NRC Regulatory Guide 1.3.

Containment leak into condenser via main steam line, condenser leak to the environment.

Control room air filtration system (see Figure 4).

EAB, LPZ, and CR doses calculated.
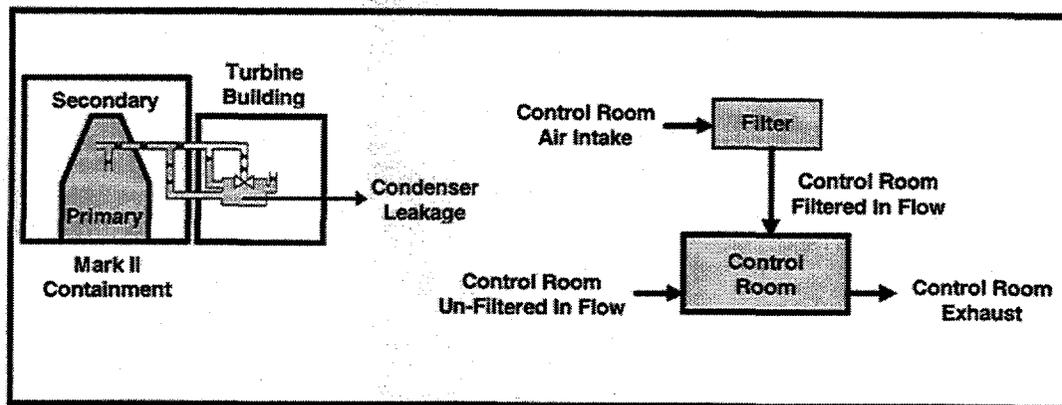
Figure 4. BWR-Mark II Containment Control Room Detail

Source Term

Release fractions and timing:	TID-14844, Table IV with modifications per NRC Regulatory Guide 1.3 and further modified as described below.
Start of release:	0.0000 hr
Iodine fractions:	1.0000

Fraction of released iodine chemical form:

Elemental:	0.9100
Organic:	0.0400
Aerosol:	0.0500

Inventory:	TID-14844 example normalized core inventory modified as follows: ^{131}I only
Reactor power:	3441 MWth

Plant Model

Containment volume:	0.3892E+06 ft^3
Effective condenser volume:	0.9860E+05 ft^3
Control room volume:	0.1100E+06 ft^3

Environment

Containment leakage:	Piping	from: Containment	to: Condenser
Condenser leakage:	Air leakage	from: Condenser	to: Environment
Filter:	Filtered pathway	from: Environment	to: Control room

CR unfiltered inflow:	Forced air	from: Environment	to: Control room
CR exhaust:	Air leakage	from: Control room	to: Environment

Scenario Description

Containment leak rate:	1.851%/day		
Condenser leak rate:	0.7666 cfm		
Filter flow rate:	5800 cfm		
Filter efficiencies:	Elemental iodine	99.0000%	
	Organic iodine	0.0000%	
	Aerosols	99.0000%	
CR unfiltered inflow:	10 cfm		
CR exhaust:	5810 cfm		

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1100E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.5200E-04
8.0000	0.3600E-04
24.0000	0.1600E-04
96.0000	0.5300E-05

Filter #1 X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.3320E-03
8.0000	0.1960E-03
24.0000	0.7640E-04
96.0000	0.2190E-04

Success Criteria

All of the RADTRAD-calculated EAB, LPZ, and CR doses must equal the doses calculated by HABIT within ± 5.0%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 12		RADTRAD	HABIT
EAB	Thyroid (rem)	6.22	6.26
	TEDE (rem)	.191	0.192
LPZ	Thyroid (rem)	2054	2050
	TEDE (rem)	63.1	63.1
CR	Thyroid (rem)	279	277
	TEDE (rem)	8.5	8.44

3.3.22 Acceptance Test Case 13

Problem Description

BWR-Mark II containment (see Figure 3).

Instantaneous, modified TID-14844 (^{131}I only) release into containment.

Release begins at reactor shutdown.

No explicit calculation of removal mechanisms in the containment, but 50% of the released iodine is deposited in accordance with NRC Regulatory Guide 1.3.

Pipe deposition with user-defined deposition rates as determined by Cline's model.

Containment leak into condenser via main steam line, condenser leak to the environment.

Control room air filtration system (see Figure 4).

EAB, LPZ, and CR doses calculated.

Source Term

Release fractions and timing:	TID-14844, Table IV with modifications per NRC Regulatory Guides 1.3 and 1.4 and further modified as described below.
Start of release:	0.0000 hr
Iodine fractions:	1.0000

Fraction of released iodine chemical form:

Elemental:	0.8760
Organic:	0.0740
Aerosol:	0.0500

Inventory:	TID-14844 example normalized core inventory modified as follows: ^{131}I only
Reactor power:	3441 MWth

Plant Model

Containment volume:	0.3892E+06 ft^3
Effective condenser volume:	0.9860E+05 ft^3
Control room volume:	0.1100E+06 ft^3

Environment

Containment leakage:	Piping	from: Containment	to: Condenser
Condenser leakage:	Air leakage	from: Condenser	to: Environment
Filter:	Filtered pathway	from: Environment	to: Control room
CR unfiltered inflow:	Forced air	from: Environment	to: Control room
CR exhaust:	Air leakage	from: Control room	to: Environment

Scenario Description

Containment leak rate:	1.85%/day
Condenser leak rate:	0.7666 cfm

Pipe deposition:	Time	Decontamination factors (Efficiency)			
	Hours	Aerosol	Elemental	Organic	
	0-40	900.	900.	1.660	(40%)
	40-100	900.	900.	1.428	(30%)
	100-200	900.	900.	1.176	(15%)
	200-400	900.	900.	1.053	(5%)
	400-	900.	900.	1.0	(0%)

Filter flow rate: 5800 cfm

Filter efficiencies:
Elemental iodine 99.0000%
Organic iodine 0.0000%
Aerosols 99.0000%

CR unfiltered inflow: 10 cfm

CR exhaust: 5810 cfm

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1100E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.5200E-04
8.0000	0.3600E-04
24.0000	0.1600E-04
96.0000	0.5300E-05

Filter # 1 X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.3320E-03
8.0000	0.1960E-03
24.0000	0.7640E-04
96.0000	0.2190E-04

Success Criteria

All of the RADTRAD-calculated EAB, LPZ, and CR doses must equal the doses calculated by HABIT within ± 5.0%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 13		RADTRAD	HABIT
EAB	Thyroid (rem)	0.283	0.277
	TEDE (rem)	0.0087	0.0085
LPZ	Thyroid (rem)	147	145
	TEDE (rem)	4.52	4.45
CR	Thyroid (rem)	376	372
	TEDE (rem)	11.5	11.3

3.3.23 Acceptance Test Case 13B

Problem Description

BWR-Mark II containment (see Figure 3).
Modified NUREG-1465 BWR (^{131}I only) release into containment.
Release begins at reactor shutdown.
Pipe deposition with user-defined deposition rates as determined by Cline's model [Cl91].
Containment leak into condenser via main steam line, condenser leak to the environment.
Control room air filtration system (see Figure 4).
EAB, LPZ, and CR doses calculated.

Source Term

Release fractions and timing:	NUREG-1465 Tables 3.11 and 3.13 with modifications.
Start of release:	0.0000 hr
Iodine fractions:	1.0000

Fraction of released iodine chemical form:

Elemental:	0.0128
Organic:	0.0372
Aerosol:	0.9500

Inventory: Normalized MACCS sample 3578 MWth BWR core inventory modified as follows:

^{131}I only

Reactor power: 3441 MWth

Plant Model

Containment volume:	0.3892E+06 ft^3
Effective condenser volume:	0.9860E+05 ft^3
Control room volume:	0.1100E+06 ft^3

Environment

Containment leakage:	Piping	from: Containment	to: Condenser
Condenser leakage:	Air leakage	from: Condenser	to: Environment
Filter:	Filtered pathway	from: Environment	to: Control room
CR unfiltered inflow:	Forced air	from: Environment	to: Control room
CR exhaust:	Air leakage	from: Control room	to: Environment

Scenario Description

Containment leak rate:	1.851%/day
Condenser leak rate:	0.7666 cfm

Pipe deposition:	Time	Decontamination Factors (Efficiency)			
	(hr)	Aerosol	Elemental	Organic	
	0-48	900.	900.	5.555	(82%)
	48-96	900.	900.	2.707	(63%)
	96-200	900.	900.	1.639	(39%)
	200-300	900.	900.	1.219	(18%)
	300-	900.	900.	1.0417	(4%)

Filter flow rate: 5800 cfm

Filter efficiencies:
Elemental iodine	99.0000%
Organic iodine	0.0000%
Aerosols	99.0000%

CR unfiltered inflow: 10 cfm

CR exhaust: 5810 cfm

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1100E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.5200E-04
8.0000	0.3600E-04
24.0000	0.1600E-04
96.0000	0.5300E-05

Filter # 1 X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.3320E-03
8.0000	0.1960E-03
24.0000	0.7640E-04
96.0000	0.2190E-04

Success Criteria

All of the RADTRAD-calculated EAB, LPZ, and CR doses must equal the doses calculated by HABIT within ± 5.0%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 13B		RADTRAD	HABIT
EAB	Thyroid (rem)	0.0175	0.0151
	TEDE (rem)	0.00040	0.00046
LPZ	Thyroid (rem)	87.0	86.5
	TEDE (rem)	2.67	2.6
CR	Thyroid (rem)	213	211
	TEDE (rem)	6.48	6.44

3.3.24 Acceptance Test Case 14

Problem Description

BWR-Mark II containment (see Figure 3).

Instantaneous, modified TID-14844 (^{131}I only) release into containment.

Release begins at reactor shutdown.

No explicit calculation of removal mechanisms in the containment, but 50% of the released iodine is deposited in accordance with NRC Regulatory Guide 1.3.

Pipe deposition using the Brockmann [Br91] and Bixler [Bi95] models.

Containment leak into condenser via main steam line, condenser leak to the environment.

Control room air filtration system (see Figure 4).

EAB, LPZ, and CR doses calculated.

Source Term

Release fractions and timing:	TID-14844, Table IV per NRC Regulatory Guide 1.4 modifications and further modified as described below.
Start of release:	0.0000 hr
Iodine fractions:	1.0000

Fraction of released iodine chemical form:

Elemental:	0.9100
Organic:	0.0400
Aerosol:	0.0500

Inventory:	TID-14844 example normalized core inventory modified as follows: [131]I only
Reactor power:	3441 MWth

Plant Model

Containment volume:	03892E+06 ft^3
Effective condenser volume:	09860E+05 ft^3
Control room volume:	01100E+06 ft^3

Environment

Containment leakage:	Piping	from: Containment	to: Condenser
Condenser leakage:	Air leakage	from: Condenser	to: Environment
Filter:	Filtered pathway	from: Environment	to: Control room
CR unfiltered inflow:	Forced air	from: Environment	to: Control room
CR exhaust:	Air leakage	from: Control room	to: Environment

Scenario Description

Containment leak rate:	1.851%/day
Condenser leak rate:	0.7666 cfm
Pipe deposition:	Pipe surface area = 500,000 ft^2
	Pipe volume = 98,6011 ft^3
	Pipe flow = 0.767 cfm
	Pipe pressure = 1.0 atm
	Pipe temperature = 548° F
Filter flow rate:	5800 cfm

		Filter efficiencies:	Elemental iodine	99.0000%

Filter efficiencies: Elemental iodine   99.0000%
                        Organic iodine   0.0000%
                        Aerosols   99.0000%

CR unfiltered inflow: 10 cfm

CR exhaust: 5810 cfm

Dose Parameters

EAB X/Q values: Time (hr)   X/Q (s/m^3)

                        0.0000   0.1100E-02
                        2.0000   0.0000E+00

LPZ X/Q values: Time (hr)   X/Q (s/m^3)

                        0.0000   0.5200E-04
                        8.0000   0.3600E-04
                        24.0000   0.1600E-04
                        96.0000   0.5300E-05

Filter #1 X/Q values: Time (hr)   X/Q (s/m^3)

                        0.0000   0.3320E-03
                        8.0000   0.1960E-03
                        24.0000   0.7640E-04
                        96.0000   0.2190E-04

Success Criteria

Deposition rate should be found to be reasonable

Acceptance Criteria

If the success criteria are not met in the RADTRAD version under test, the software will be still be acceptable to the NRC. However, SNL will be responsible for determining the cause of the failure and correction will be expected before project closeout.

Results

		RADTRAD Case 14	RADTRAD Case 12	RADTRAD Case 13
EAB	Thyroid (rem)	0.118	6.22	0.283
	TEDE (rem)	0.003	0.191	0.0087
LPZ	Thyroid (rem)	39.00	2054	147
	TEDE (rem)	1.2	63.1	4.52
CR	Thyroid (rem)	97.6	279	376
	TEDE (rem)	3.00	8.5	11.5

The results of case 12 are dominated by the elemental iodine release. In cases 13 and 14, where the elemental iodine is deposited on the pipe and condenser walls, the dose falls significantly. In case 13 the deposited iodine is allowed to revaporize in an organic form, which is not trapped by filters; thus the dose in 13 is higher than 14. This effect also explains why the control room dose in case 13 is higher than case 12 and indicates that revaporization is an important phenomenon.

3.3.25 Acceptance Test Case 14B

Problem Description

BWR-Mark II containment (see Figure 3).
Modified NUREG-1465 BWR (^{131}I only) release into containment.
Release begins at reactor shutdown.
Pipe deposition using the Brockmann [Br91] and Bixler [Bi95] models.
Containment leak into condenser via main steam line, condenser leak to the environment.
Control room air filtration system (see Figure 4).
EAB, LPZ, and CR doses calculated.

Source Term

Release fractions and timing:	NUREG-1465 Tables 3.11 and 3.13 with modification as described below.
Start of release:	0.0000 hr
Iodine fractions:	1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory:	Normalized MACCS sample 3578 MWth BWR core inventory modified as follows:
	^{131}I only
Reactor power:	3441 MWth

Plant Model

Containment volume:	0.3892E+06 ft^3
Effective condenser volume:	0.9860E+05 ft^3
Control room volume:	0.1100E+06 ft^3
Environment	

Containment leakage:	Piping	from: Containment	to: Condenser
Condenser leakage:	Air leakage	from: Condenser	to: Environment
Filter:	Filtered pathway	from: Environment	to: Control room
CR unfiltered inflow:	Forced air	from: Environment	to: Control room
CR exhaust:	Air leakage	from: Control room	to: Environment

Scenario Description

Containment leak rate:	1.85%/day
Condenser leak rate:	0.7666 cfm
Pipe deposition:	Pipe surface area = 500,000 ft^2
	Pipe volume = 98,6011 ft^3
	Pipe flow = 0.766 cfm
	Pipe pressure = 1.0 atm
	Pipe temperature = 548°F
Filter flow rate:	5800 cfm

Filter efficiencies:	Elemental iodine	99.0000%
	Organic iodine	0.0000%
	Aerosols	99.0000%

| CR unfiltered inflow: | 10 cfm |

| CR exhaust: | 5810 cfm |

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1100E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.5200E-04
8.0000	0.3600E-04
24.0000	0.1600E-04
96.0000	0.5300E-05

Filter #1 X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.3320E-03
8.0000	0.1960E-03
24.0000	0.7640E-04
96.0000	0.2190E-04

Success Criteria

The deposition rate should be found to be reasonable.

Acceptance Criteria

If the success criteria are not met in the RADTRAD version under test, the software will be still be acceptable to the NRC. However, SNL will be responsible for determining the cause of the failure and correction will be expected before project closeout.

Results

		RADTRAD Case 13B	RADTRAD Case 14B
EAB	Thyroid (rem)	0.0175	0.0040
	TEDE (rem)	0.00040	0.00012
LPZ	Thyroid (rem)	87.1	4.59
	TEDE (rem)	2.67	0.141
CR	Thyroid (rem)	213.	4.66
	TEDE (rem)	6.48	0.142
Pipe and condenser	I_2 (atom	0.8787e+21	0.3326e+22
Deposition	Organic (atom)	0.2431 e+21	0.6713e+20
@ 720 hr	Aerosol (kg)	0.1419 e-01	0.1417e-01

Case 14B removes aerosols very similarly to case 13B; however, these scenarios are depositing materials not only on the steam line walls but also within the condenser. Thus where the Cline model assumes total aerosol deposition, the Brockmann model should get very similar results, just because of the very large surface areas involved. In cases where only the pipe is involved, aerosol deposition percentages are more like 70%. As can be seen from this table, the elemental (I_2) depositions are also similar, the difference being the transformation of I_2 into an organic form. Likewise, the total organic deposition is different due to the revaporization in the Cline model of case 13B. The total result is that the doses for case 13B are higher than those for case 14B.

3.3.26 Acceptance Test Case 15

Problem Description

BWR-Mark II containment (see Figure 5).

Modified NUREG-1465 BWR (^{131}I only) release into containment.

Release begins at reactor shutdown.

Auxiliary building exhaust filter #1.

Containment leak into auxiliary building via ECCS leak; auxiliary building leak to the environment.

EAB and LPZ doses calculated.
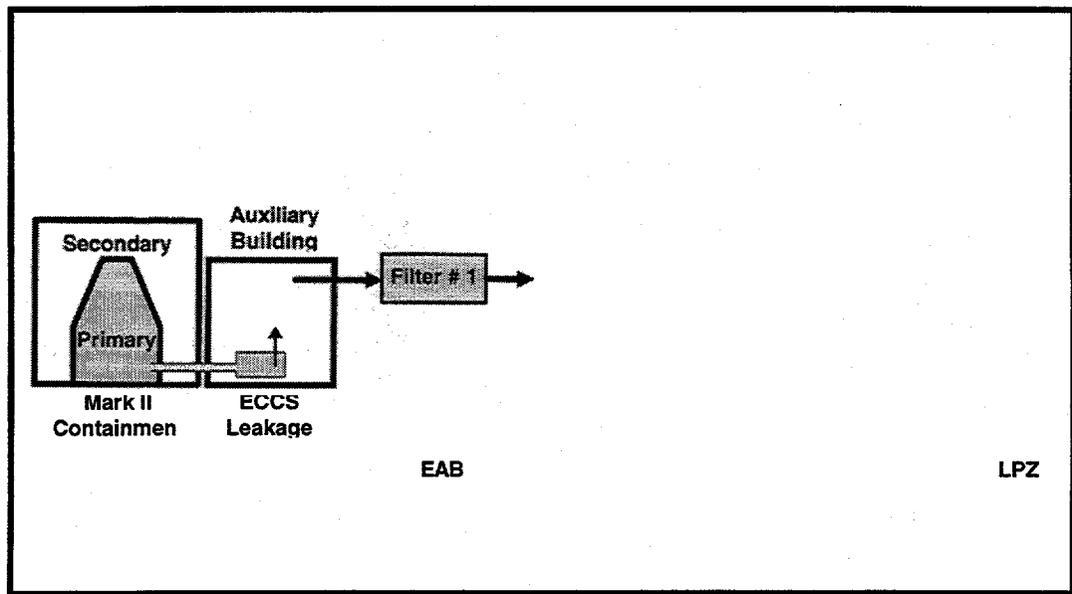
Figure 5. BWR-Mark II Containment ECCS Leakage

Source Term

Release fractions and timing:	NUREG-1465, Tables 3.11 and 3.13 with modifications as described below.
Start of release:	0.0000 hr
Iodine fractions:	1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory:	Normalized MACCS sample 3578 MWth BWR core inventory modified as follows:
	^{131}I only
Reactor power:	3441 MWth

Plant Model

Containment volume:	0.3892E+06 ft^3		
Auxiliary bldg. volume:	0.1000E+07 ft^3		
Environment			
Containment leakage:	Piping	from: Containment	to: Auxiliary bldg.
Filter # 1:	Filtered Pathway	from: Auxiliary bldg.	to: Environment

Scenario Description

Containment leak rate: 0.53%/day

Filter # 1 flow rate: 4000 cfm

Filter efficiencies:

Elemental iodine	99.0000%
Organic iodine	0.0000%
Aerosols	99.0000%

In this case an additional auxiliary building inlet was added to balance the exit airflow. This should cause a slightly higher dose to the auxiliary building. Based on the result, the added dose is negligible.

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1100E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.5200E-04
8.0000	0.3600E-04
24.0000	0.1600E-04
96.0000	0.5300E-05

Success Criteria

All of the RADTRAD-calculated EAB and LPZ doses must equal the doses calculated by HABIT within ± 5.0%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 15		RADTRAD	HABIT
EAB	Thyroid (rem)	3.41	3.41
	TEDE (rem)	0.105	0.104
LPZ	Thyroid (rem)	82.2	82.2
	TEDE (rem)	2.53	2.53

3.3.27 Acceptance Test Case 16

Problem Description

BWR-Mark II containment (see Figure 5).

Modified NUREG-1465 BWR (^{131}I only) release into containment.

Release begins at reactor shutdown.

Auxiliary building exhaust filter #1.

Containment leak into auxiliary building via ECCS leak; auxiliary building leak to the environment.

Control room air filtration system (see Figure 6).

EAB, LPZ, and CR doses calculated.
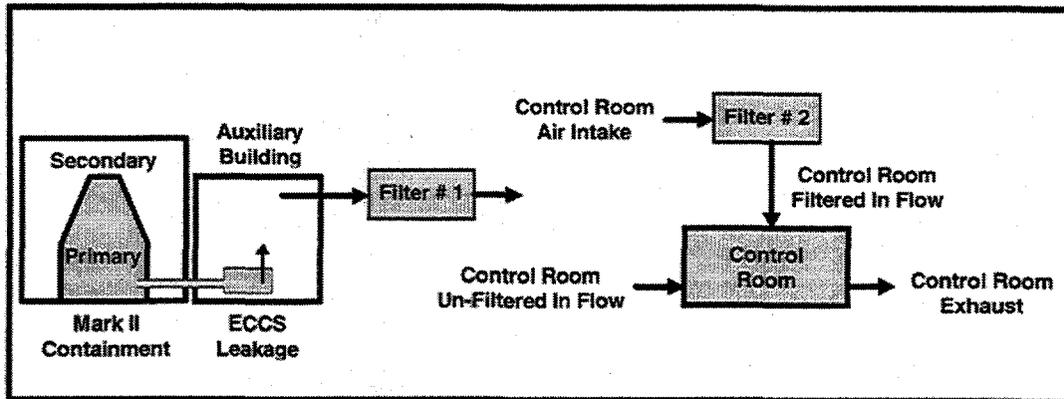
Figure 6. BWR-Mark II Containment Control Room Detail

Source Term

Release fractions and timing: NUREG-1465, Tables 3.11 and 3.13 with modifications as described below.

Start of release: 0.0000 hr

Iodine fractions: 1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory: Normalized MACCS sample 3578 MWth BWR core inventory modified as follows:

^{131}I only

Reactor power: 3441 MWth

Plant Model

Containment volume: 0.3892E+06 ft^3

Auxiliary building volume: 0.1000E+07 ft^3

Control room volume: 0.1100E+06 ft^3

Environment

Containment leakage:	Piping	from: Containment	to: Auxiliary bldg.
Filter # 1:	Filtered pathway	from: Auxiliary bldg.	to: Environment
Filter # 2:	Filtered pathway	from: Environment	to: Control room

CR unfiltered inflow:	Forced air	from: Environment	to: Control room
CR leakage:	Air leakage	from: Control room	to: Environment

Scenario Description

Containment leak rate:	0.5300%/day
Filter #1 flow rate:	4000 cfm

Filter #1 efficiencies:	Elemental iodine	99.0000%
	Organic iodine	0.0000%
	Aerosols	99.0000%

Filter #2 flow rate:	5800 cfm

Filter #2 efficiencies:	Elemental iodine	99.0000%
	Organic iodine	0.0000%
	Aerosols	99.0000%

CR unfiltered inflow:	10 cfm
CR exhaust:	5810 cfm

Dose Parameters

EAB X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.1100E-02
	2.0000	0.0000E+00

LPZ X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.5200E-04
	8.0000	0.3600E-04
	24.0000	0.1600E-04
	96.0000	0.5300E-05

Filter #2 X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.3320E-03
	8.0000	0.1960E-03
	24.0000	0.7640E-04
	96.0000	0.2190E-04

Success Criteria

All of the RADTRAD-calculated EAB, LPZ, and CR doses must equal the doses calculated by HABIT within ± 5.0%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 16		RADTRAD	HABIT
EAB	Thyroid (rem)	3.41	3.41
	TEDE (rem)	.105	.105
LPZ	Thyroid (rem)	82.2	82.2
	TEDE (rem)	2.53	2.53
CR	Thyroid (rem)	44.8	44.2
	TEDE (rem	1.37	1.35

3.3.28 Acceptance Test Case 17

Problem Description

Acceptance test deleted per NRC's request.

3.3.29 Acceptance Test Case 18

Problem Description

Acceptance test deleted per NRC's request.

3.3.30 Acceptance Test Case 19

Problem Description

Advanced PWR design (see Figure 7).

Modified NUREG-1465 PWR (^{131}I only) release into sprayed [1] containment region.

Release begins at reactor shutdown.

Containment annulus exhaust filter.

Sprayed containment region mixes with unsprayed region; both leak to the environment and annulus; annulus also exhausts to the environment.

EAB and LPZ doses calculated.
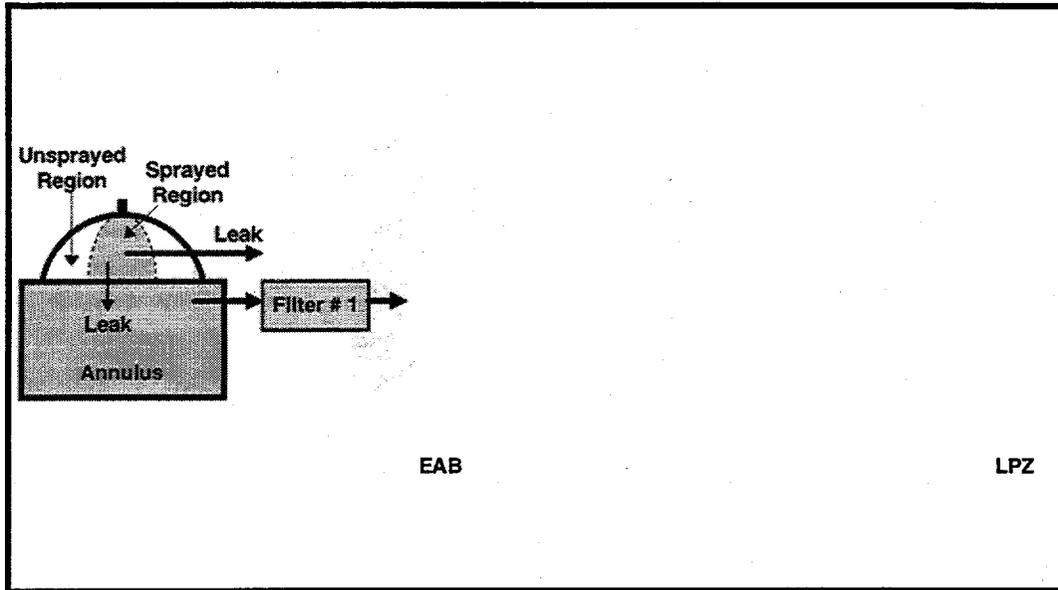
Figure 7. Advanced PWR Containment Leakage

Source Term

Release fractions and timing:	NUREG-1465, Tables 3.12 and 3.13 with modifications as described below.
Start of release:	0.0000 hr
Iodine fractions:	1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory:	Normalized MACCS sample 3412 MWth PWR core inventory modified as follows:
	^{131}I only.
Reactor power:	3992 MWth

---

[1] For this and the next several test cases, the (un)sprayed containment region or (un)sprayed containment only refers to the containment region that can or cannot be sprayed. It does not indicate that sprays are being modeled. The sprays will be modeled in test cases 23 and 24.

Plant Model

Sprayed
    containment volume: $0.2740E+07$ ft^3

Unsprayed
    containment volume: $0.6011E+06$ ft^3

Annulus volume: $0.6162E+06$ ft^3

Environment

Sprayed containment leakage:

Bypass:	Air leakage	from: Sprayed	to: Environment
Annulus:	Air leakage	from: Sprayed	to: Annulus

Unsprayed containment leakage:

Bypass:	Air leakage	from: Unsprayed	to: Environment
Annulus:	Air leakage	from: Unsprayed	to: Annulus

Containment mixing:

Sprayed:	Air leakage	from: Sprayed	to: Unsprayed
Unsprayed:	Air leakage	from: Unsprayed	to: Sprayed

Filter # 1:	Filtered pathway	from: Annulus	to: Environment

Scenario Description

Containment mixing:

Time (hr)	Sprayed to unsprayed (%/day)	Unsprayed to sprayed (%/day)
0.000	0.1053E+04	0.4800E+04
0.1667	0.4056E+04	0.1845E+04
0.500	0.4425E+04	0.2016E+05
1.175	0.2951E+04	0.1344E+05
1.800	0.1053E+04	0.4800E+04

Sprayed zone leak rate:

Time (hr)	Bypass rate (%/day)	Annulus rate (%/day)
0.0000	0.5000E-01	0.4500
24.0000	0.2500E-01	0.2250

Unsprayed zone leak rate:

Time (hr)	Bypass rate (%/day)	Annulus rate (%/day)
0.0000	0.5000E-01	0.4500
24.0000	0.2500E-01	0.2250

Annulus exhaust:

Time (hr)	Filter #1 Flow rate
0.0000	0 cfm
0.0278	14000 cfm
0.2778	1000 cfm

Filter #1 efficiencies:

Elemental iodine	0.0000%
Organic iodine	0.0000%
Aerosols	99.0000%

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m³)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Success Criteria

All of the RADTRAD-calculated EAB and LPZ doses must equal the doses calculated by HABIT within ± 10.0%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 19		RADTRAD	HABIT
EAB	Thyroid (rem)	314	315
	TEDE (rem)	9.62	9.66
LPZ	Thyroid (rem)	3485	3480
	TEDE (rem	107	107

3.3.31 Acceptance Test Case 20

Problem Description

Advanced PWR design (see Figure 7).

NUREG-1465 PWR release into sprayed[2] containment region.

Release begins at reactor shutdown.

Containment annulus exhaust filter.

Sprayed containment region mixes with unsprayed region; both leak to the environment and annulus; annulus also exhausts to the environment.

EAB and LPZ doses calculated.

Source Term

Release fractions and timing: NUREG-1465, Tables 3.12 and 3.13.

Start of release: 0.0000 hr

Iodine fractions: 1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory: Normalized MACCS sample 3412 MWth PWR core inventory.

Reactor power: 3992 MWth

Plant Model

Sprayed
   containment volume: $0.2740E+07 \ ft^3$

Unsprayed
   containment volume: $00.6011E+06 \ ft^3$

Annulus volume: $00.6162E+06 \ ft^3$

Environment

Sprayed containment leakage:

Bypass:	Air leakage	from: Sprayed	to: Environment
Annulus:	Air leakage	from: Sprayed	to: Annulus

Unsprayed containment leakage:

Bypass:	Air leakage	from: Unsprayed	to: Environment
Annulus:	Air leakage	from: Unsprayed	to: Annulus

Containment mixing:

Sprayed:	Air Leakage	from: Sprayed	to: Unsprayed
Unsprayed:	Air Leakage	from: Unsprayed	to: Sprayed

Filter # 1:   Filtered Pathway   from: Annulus   to: Environment

---

[2] For this and the next several test cases, the (un)sprayed containment region or (un)sprayed containment only refers to the containment region that can or cannot be sprayed. It does not indicate that sprays are being modeled. The sprays will be modeled in test cases 23 and 24.

Scenario Description

Containment mixing:

Time (hr)	Sprayed to unsprayed (%/day)	Unsprayed to sprayed (%/day)
0.000	0.1053E+04	0.4800E+04
0.1667	0.4056E+04	0.1845E+05
0.500	0.4425E+04	0.2016E+05
1.175	0.2951E+04	0.1344E+05
1.800	0.1053E+04	0.4800E+04

Sprayed zone leak rate:

Time (hr)	Bypass rate (%/day)	Annulus rate (%/day)
0.0000	0.5000E-01	0.4500
24.0000	0.2500E-01	0.2250

Unsprayed zone leak rate:

Time (hr)	Bypass rate (%/day)	Annulus rate (%/day)
0.0000	0.5000E-01	0.4500
24.0000	0.2500E-01	0.2250

Annulus exhaust:

Time (hr)	Filter #1 flow rate (cfm)
0.0000	0
0.0278	14000
0.2778	1000

Filter #1 efficiencies:

Elemental iodine	0.0000%
Organic iodine	0.0000%
Aerosols	99.0000%

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Success Criteria

All of the RADTRAD-calculated EAB and LPZ doses must equal the doses calculated by HABIT within ± 10.0%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 20		RADTRAD	HABIT
EAB	Thyroid (rem)	459	460
	TEDE (rem)	22.7	22.7
LPZ	Thyroid (rem)	5070	5070
	TEDE (rem)	342	342

3.3.32 Acceptance Test Case 21

Problem Description

Advanced PWR design (see Figure 7).

NUREG-1465 PWR release into sprayed[3] containment region.

Release begins at reactor shutdown.

Containment annulus exhaust filter.

Sprayed containment region mixes with unsprayed region; both leak to the environment and annulus; annulus also exhausts to the environment.

Control room air filtration system (see Figure 8).

EAB, LPZ, and CR doses calculated.
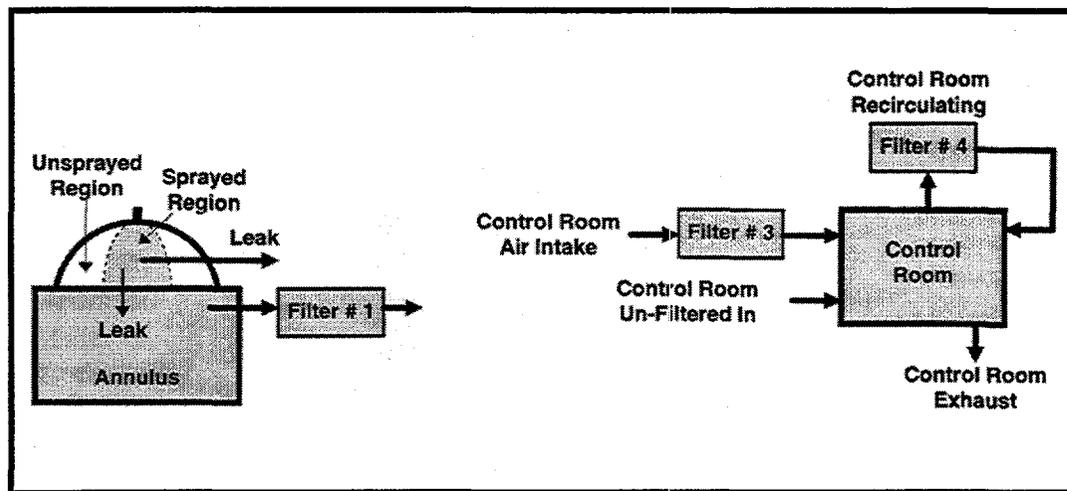
Figure 8. Advanced PWR Control Room Detail

Source Term

Release fractions and timing: NUREG-1465, Tables 3.12 and 3.13.

Start of release: 0.0000 hr

Iodine fractions: 1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory: Normalized MACCS sample 3412 MWth PWR core inventory.

Reactor power: 3992 MWth

Plant Model

Sprayed
containment volume: $0.2740E+07$ ft^3

Unsprayed
containment volume: $0.6011E+06$ ft^3

---

[3] For this and the next several test cases, the (un)sprayed containment region or (un)sprayed containment only refers to the containment region that can or cannot be sprayed. It does not indicate that sprays are being modeled. The sprays will be modeled in test cases 23 and 24.

Annulus volume: 0.6169E+06 ft³

Control room volume: 0.673E+05 ft³

Environment

Sprayed containment leakage:
    Bypass: Air leakage   from: Sprayed   to: Environment
    Annulus: Air leakage   from: Sprayed   to: Annulus

Unsprayed containment leakage:
    Bypass: Air leakage   from: Unsprayed   to: Environment
    Annulus: Air leakage   from: Unsprayed   to: Annulus

Containment mixing:
    Sprayed: Air leakage   from: Sprayed   to: Unsprayed
    Unsprayed: Air leakage   from: Unsprayed   to: Sprayed

Filter #1:   Filtered pathway   from: Annulus   to: Environment

Filter #2:   Filtered pathway   from: Environment   to: Control room

Filter #3:   Recirculation filter   from: Control room   to: Control room

CR exhaust: Air leakage   from: Control room   to: Environment

CR unfiltered inflow: Air leakage   from: Environment   to: Control room

Scenario Description

Containment mixing:

Time (hr)	Sprayed to unsprayed (%/day)	Unsprayed to sprayed (%/day)
0.000	0.1053E+04	0.4800E+04
0.1667	0.4056E+04	0.1845E+05
0.500	0.4425E+04	0.2016E+05
1.175	0.2951E+04	0.1344E+05
1.800	0.1053E+04	0.4800E+04

Sprayed zone leak rate:

Time (hr)	Bypass rate (%/day)	Annulus rate (%/day)
0.0000	0.5000E-01	0.4500
24.0000	0.2500E-01	0.2250

Unsprayed zone leak rate:

Time (hr)	Bypass rate (%/day)	Annulus rate (%/day)
0.0000	0.5000E-01	0.4500
24.0000	0.2500E-01	0.2250

Annulus exhaust:

Time (hr)	Filter #1 Flow rate (cfm)
0.0000	0
0.0278	14000
0.2778	1000

Filter #1 efficiencies:

Elemental iodine	0.0000%
Organic iodine	0.0000%
Aerosols	99.0000%

Filter #2 flow rate: 2000 cfm

Filter #3 efficiencies:

Elemental iodine	95.0000%
Organic iodine	95.0000%
Aerosols	99.0000%

Filter #4 flow rate:	4000 cfm	
Filter #4 efficiencies:	Elemental iodine	95.0000%
	Organic iodine	95.0000%
	Aerosols	99.0000%
CR exhaust:	2010 cfm	
CR unfiltered inflow:	10 cfm	

Dose Parameters

EAB X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.1000E-02
	2.0000	0.0000E+00

LPZ X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.1350E-03
	8.0000	0.1000E-03
	24.0000	0.5400E-04
	96.0000	0.2200E-04

Filter #2 X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.2200E-02
	2.0000	0.1500E-02
	8.0000	0.1300E-02
	24.0000	0.8400E-03
	96.0000	0.4800E-03

Success Criteria

All of the RADTRAD-calculated EAB, LPZ, and CR doses must equal the doses calculated by HABIT within ± 10.0%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 21		RADTRAD	HABIT
EAB	Thyroid (rem)	459	460
	TEDE (rem)	22.7	22.7
LPZ	Thyroid (rem)	5070	5070
	TEDE (rem)	342	342
CR	Thyroid (rem)	662	669
	TEDE (rem)	59.4	59.7

3.3.33 Acceptance Test Case 22

Problem Description

Advanced PWR design (see Figure 7).

NUREG-1465 PWR release into sprayed[4] containment region.

Release begins at reactor shutdown.

Containment annulus exhaust filter.

Sprayed containment region mixes with unsprayed region, both leak to the environment and annulus, annulus also exhausts to the environment.

Control room air filtration system (see Figure 8).

User-defined natural deposition in sprayed and unsprayed containment regions.

Source Term

Release fractions and timing: NUREG-1465, Tables 3.12 and 3.13.

Start of release: 0.0000 hr

Iodine fractions: 1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory: Normalized MACCS sample 3412 MWth PWR core inventory.

Reactor power: 3992 MWth

Plant Model

Sprayed
containment volume: $0.2740E+07 \ ft^3$

Unsprayed
containment volume: $0.6011E+06 \ ft^3$

Annulus volume: $0.6162E+06 \ ft^3$

Control room volume: $0.6731E+05 \ ft^3$

Environment

Sprayed containment leakage:

Bypass:	Air leakage	from: Sprayed	to: Environment
Annulus:	Air leakage	from: Sprayed	to: Annulus

Unsprayed containment leakage:

Bypass:	Air leakage	from: Unsprayed	to: Environment
Annulus:	Air leakage	from: Unsprayed	to: Annulus

Containment mixing:

Sprayed:	Air Leakage	from: Sprayed	to: Unsprayed
Unsprayed:	Air Leakage	from: Unsprayed	to: Sprayed

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[4] For this and the next several test cases, the (un)sprayed containment region or (un)sprayed containment only refers to the containment region that can or cannot be sprayed. It does not indicate that sprays are being modeled. The sprays will be modeled in test cases 23 and 24.

Filter #1:	Filtered pathway	from: Annulus	to: Environment
Filter #2:	Filtered pathway	from: Environment	to: Control Room
Filter #3:	Recirculation Filter	from: Control Room	to: Control Room
CR exhaust:	Air leakage	from: Control room	to: Environment
CR unfiltered inflow:	Air leakage	from: Environment	to: Control Room

Scenario Description

Containment mixing:

Time (hr)	Sprayed to unsprayed (%/day)	Unsprayed to sprayed (%/day)
0.000	0.1053E+04	0.4800E+04
0.1667	0.4056E+04	0.1845E+05 day
0.500	0.4425E+04	0.2016E+05
1.175	0.2951E+04	0.1344E+05
1.800	0.1053E+04	0.4800E+04

Sprayed zone leak rate:

Time (hr)	Bypass rate (%/day)	Annulus rate (%/day)
0.0000	0.5000E-01	0.4500
24.0000	0.2500E-01	0.2250

Unsprayed zone leak rate:

Time (hr)	Bypass rate (%/day)	Annulus rate (%/day)
0.0000	0.5000E-01	0.4500
24.0000	0.2500E-01	0.2250

Natural deposition
aerosol removal rate: 0.15 / hr

Annulus exhaust:

Time (hr)	Filter #1 flow rate
0.0000	0 cfm
0.0278	14000 cfm
0.2778	1000 cfm

Filter #1 efficiencies:

Elemental iodine	0.0000%
Organic iodine	0.0000%
Aerosols	99.0000%

Filter #2 flow rate: 2000 cfm

Filter #2 efficiencies:

Elemental iodine	95.0000%
Organic iodine	95.0000%
Aerosols	99.0000%

Filter #3 flow rate: 4000 cfm

Filter #3 efficiencies:

Elemental iodine	95.0000%
Organic iodine	95.0000%
Aerosols	99.0000%

CR exhaust: 2010 cfm

CR unfiltered inflow: 10 cfm

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Filter #2 X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.2200E-02
2.0000	0.1500E-02
8.0000	0.1300E-02
24.0000	0.8400E-03
96.0000	0.4800E-03

Success Criteria

All of the RADTRAD-calculated EAB, LPZ, and CR doses must equal the doses calculated by HABIT within ± 10.0%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 22		RADTRAD	HABIT
EAB	Thyroid (rem)	424	425
	TEDE (rem)	21.1	21.1
LPZ	Thyroid (rem)	1845	1840
	TEDE (rem)	179	179
CR	Thyroid (rem)	439	436
	TEDE (rem)	50.0	49.7

3.3.34 Acceptance Test Case 23

Problem Description

Advanced PWR design (see Figure 7).
NUREG-1465 PWR release into sprayed containment region.
Release begins at reactor shutdown.
Containment annulus exhaust filter.
Sprayed containment region mixes with unsprayed region; both leak to the environment and annulus; annulus also exhausts to the environment.
Control room air filtration system (see Figure 8).
User-defined natural deposition in unsprayed containment region.
User-defined spray removal coefficients.

Source Term

Release fractions and timing: NUREG-1465, Tables 3.12 and 3.13.

Start of release: 0.0000 hr

Iodine fractions: 1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory: Normalized MACCS sample 3412 MWth PWR core inventory.

Reactor power: 3992 MWth

Plant Model

Sprayed
  containment volume: $0.2740E+07$ ft^3

Unsprayed
  containment volume: $0.6011E+06$ ft^3

Annulus volume: $0.6162E+06$ ft^3

Control room volume: $0.6731E+05$ ft^3

Environment

Sprayed containment leakage:

Bypass:	Air leakage	from: Sprayed	to: Environment
Annulus:	Air leakage	from: Sprayed	to: Annulus

Unsprayed containment leakage:

Bypass:	Air leakage	from: Unsprayed	to: Environment
Annulus:	Air leakage	from: Unsprayed	to: Annulus

Containment Mixing:

Sprayed:	Air leakage	from: Sprayed	to: Unsprayed
Unsprayed:	Air leakage	from: Unsprayed	to: Sprayed

Filter #1:	Filtered pathway	from: Annulus	to: Environment
Filter #2:	Filtered pathway	from: Environment	to: Control room

Filter #3:	Recirculation filter	from: Control Room	to: Control room
CR exhaust:	Air leakage	from: Control room	to: Environment
CR unfiltered inflow:	Air leakage	from: Environment	to: Control room

Scenario Description

Containment mixing:	Time (hr)	Sprayed to unsprayed (%/day)	Unsprayed to sprayed (%/day)
	0.000	0.1053E+04	0.4800E+04
	0.1667	0.4056E+04	0.1845E+05
	0.500	0.4425E+04	0.2016E+05
	1.175	0.2951E+04	0.1344E+05
	1.800	0.1053E+04	0.4800E+04

Sprayed zone leak rate:	Time (hr)	Bypass rate (%/day)	Annulus rate (%/day)
	0.0000	0.5000E-01	0.4500
	24.0000	0.2500E-01	0.2250

Unsprayed zone leak rate:	Time (hr)	Bypass rate (%/day)	Annulus rate (%/day)
	0.0000	0.5000E-01	0.4500
	24.0000	0.2500E-01	0.2250

Natural deposition aerosol removal rate:	0.15 / hr

Spray removal coefficients:	Time (hr)	Removal coefficient for aerosols and elementals (hr^{-1})
	0.0000	1.5
	0.50	12
	1.8	5
	2.0	2
	8.0	0.4

	Time (hr)	Removal coefficients for organics
	0.0000	0.00

Annulus exhaust:	Time (hr)	Filter #1 flow rate (cfm)
	0.0000	0
	0.0278	14000
	0.2778	1000

Filter #1 efficiencies:	Elemental iodine	0.0000%
	Organic iodine	0.0000%
	Aerosols	99.0000%

Filter #2 flow rate:	2000 cfm

Filter #2 efficiencies:	Elemental iodine	95.0000%
	Organic iodine	95.0000%
	Aerosols	99.0000%

Filter #4 flow rate:	4000 cfm

Filter #4 efficiencies:	Elemental iodine	95.0000%
	Organic iodine	95.0000%
	Aerosols	99.0000%

CR exhaust:	2010 cfm

CR unfiltered inflow:	10 cfm

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Filter #2 X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.2200E-02
2.0000	0.1500E-02
8.0000	0.1300E-02
24.0000	0.8400E-03
96.0000	0.4800E-03

Success Criteria

All of the RADTRAD-calculated EAB, LPZ, and CR doses must equal the doses calculated by HABIT within ± 10.0%.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

Test Case 23		RADTRAD	HABIT
EAB	Thyroid (rem)	61.7	61.7
	TEDE (rem)	4.16	4.16
LPZ	Thyroid (rem)	58.1	58.1
	TEDE (rem)	106	106
CR	Thyroid (rem)	14.1	14
	TEDE (rem)	36.2	36

3.3.35 Acceptance Test Case 24

Problem Description

Advanced PWR design (see Figure 7).

NUREG-1465 PWR release into sprayed containment region.

Release begins at reactor shutdown.

Containment annulus exhaust filter.

Sprayed containment region mixes with unsprayed region; both leak to the environment and annulus; annulus also exhausts to the environment.

Control room air filtration system (see Figure 8).

User-defined natural deposition in unsprayed containment region.

Spray removal coefficients determined from Powers model [Po93].

Source Term

Release fractions and timing:	NUREG-1465, Tables 3.12 and 3.13.
Start of release:	0.0000 hr
Iodine fractions:	1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory:	Normalized MACCS sample 3412 MWth PWR core inventory.
Reactor power:	3992 MWth

Plant Model

Sprayed containment volume:	$0.2740E+07$ ft^3
Unsprayed containment volume:	$0.6011E+06$ ft^3
Annulus volume:	$0.6162E+06$ ft^3
Control room volume:	$0.6731E+05$ ft^3

Environment

Sprayed containment leakage:

Bypass:	Air leakage	from: Sprayed	to: Environment
Annulus:	Air leakage	from: Sprayed	to: Annulus

Unsprayed containment leakage:

Bypass:	Air leakage	from: Unsprayed	to: Environment
Annulus:	Air leakage	from: Unsprayed	to: Annulus

Containment Mixing:

Sprayed:	Air leakage	from: Sprayed	to: Unsprayed
Unsprayed:	Air leakage	from: Unsprayed	to: Sprayed
Filter #1:	Filtered pathway	from: Annulus	to: Environment
Filter #2:	Filtered pathway	from: Environment	to: Control room

Filter #3:	Recirculation filter	from: Control room	to: Control room
CR exhaust:	Air leakage	from: Control room	to: Environment
CR unfiltered inflow:	Air leakage	from: Environment	to: Control room

Scenario Description

Containment mixing:	Time (hr)	Sprayed to unsprayed (%/day)	Unsprayed to sprayed (%/day)
	0.000	0.1053E+04	0.4800E+04
	0.1667	0.4056E+04	0.1845E+05
	0.500	0.4425E+04	0.2016E+05
	1.175	0.2951E+04	0.1344E+05
	1.800	0.1053E+04	0.4800E+04

Sprayed zone leak rate:	Time (hr)	Bypass rate (%/day)	Annulus rate (%/day)
	0.0000	0.5000E-01	0.4500
	24.0000	0.2500E-01	0.2250

Unsprayed zone leak rate:	Time (hr)	Bypass rate (%/day)	Annulus rate (%/day)
	0.0000	0.5000E-01	0.4500
	24.0000	0.2500E-01	0.2250

Natural deposition
aerosol removal rate: 0.1500 hr^{-1}

Powers' spray removal:
Nozzle height: 85 ft
Mean cross section: $0.3230E+05 \text{ ft}^2$
Spray volume fraction: 1.0
Confidence level: 50%

Water flow	Time	Flow rate/coverage area (FLUX)
	0.0	$0.3937E-01 \text{ cfm/ft}^2$
	3.0	0.0 cfm/ft^2

Spray removal coefficients:	Time (hr)	Removal coefficient for elementals (hr^{-1})
	0.0000	1.5
	0.50	12
	1.8	5
	2.0	2
	8.0	0.4

	Time (hr)	Removal coefficients for organics
	0.0000	0.00

Annulus exhaust:	Time (hr)	Filter #1 flow rate
	0.0000	0 cfm
	0.0278	1400 cfm
	0.2778	1000 cfm

Filter #1 efficiencies:	Elemental iodine	0.0000%
	Organic iodine	0.0000%
	Aerosols	99.0000%

Filter #2 flow rate: 2000 cfm

Filter #2 efficiencies:	Elemental iodine	95.0000%
	Organic iodine	95.0000%
	Aerosols	99.0000%

Filter #3 flow rate:	4000 cfm	
Filter #3 efficiencies:	Elemental iodine	95.0000%
	Organic iodine	95.0000%
	Aerosols	99.0000%
CR exhaust:	2010 cfm	
CR unfiltered inflow:	10 cfm	

Dose Parameters

EAB X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.1000E-02
	2.0000	0.0000E+0

LPZ X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.1350E-03
	8.0000	0.1000E-03
	24.0000	0.5400E-04
	96.0000	0.2200E-04

Filter #2 X/Q values:	Time (hr)	X/Q (s/m^3)
	0.0000	0.2200E-02
	2.0000	0.1500E-02
	8.0000	0.1300E-02
	24.0000	0.8400E-03
	96.0000	0.4800E-03

Success Criteria

The deposition rate should be found to be reasonable.

Acceptance Criteria

If the success criteria are not met in the RADTRAD version under test, the software will be still be acceptable to the NRC. However, SNL will be responsible for determining the cause of the failure and correction will be expected before project closeout.

Results

Test Case 24		RADTRAD	RADTRAD Case 23
EAB	Thyroid (rem)	68.6	61.7
	TEDE (rem)	4.54	4.16
LPZ	Thyroid (rem)	60.4	58.1
	TEDE (rem)	106	106
CR	Thyroid (rem)	14.3	14
	TEDE (rem)	36.2	36

The results are similar to those for the user-supplied spray decontamination coefficient input. This indicates that the model has the correct trends.

3.3.36 Acceptance Test Case 24A

Problem Description

Advanced PWR design (see Figure 7).
NUREG-1465 PWR release into sprayed containment region.
NUREG-1465 DRAFT PWR aerosol release into sprayed containment region.
Release begins at reactor shutdown.
Containment annulus exhaust filter.
Sprayed containment region mixes with unsprayed region; both leak to the environment and annulus; annulus also exhausts to the environment.
Control room air filtration system (see Figure 8).
User-defined natural deposition in unsprayed containment region.
Spray removal coefficients determined from Powers model [PO93].

Source Term

Release fractions and timing: NUREG-1465, Tables 3.12 and 3.13.

Start of release: 0.0000 hr

Iodine fractions: 1.0000

Fraction of released iodine chemical form:

Elemental:	0.0485
Organic:	0.0015
Aerosol:	0.9500

Inventory: Normalized MACCS sample 3412 MWth PWR core inventory.

Reactor power: 3992 MWth

Plant Model

Sprayed
containment volume: $0.2740E+07$ ft^3

Unsprayed
containment volume: $0.6011E+06$ ft^3

Annulus volume: $0.6162E+06$ ft^3

Control room volume: $0.6731E+05$ ft^3

Environment

Sprayed containment leakage:
Bypass:	Air leakage	from: Sprayed	to: Environment
Annulus:	Air leakage	from: Sprayed	to: Annulus

Unsprayed containment leakage:
Bypass:	Air leakage	from: Unsprayed	to: Environment
Annulus:	Air leakage	from: Unsprayed	to: Annulus

Containment mixing:
Sprayed:	Air leakage	from: Sprayed	to: Unsprayed
Unsprayed:	Air leakage	from: Unsprayed	to: Sprayed

Filter #1: Filtered pathway from: Annulus to: Environment

Filter #3: Filtered pathway from: Environment to: Control room

Filter #4:	Recirculation filter	from: Control room	to: Control room
CR exhaust:	Air leakage	from: Control room	to: Environment
CR unfiltered inflow:	Air leakage	from: Environment	to: Control room

Scenario Description

Containment mixing:	Time (hr)	Sprayed to unsprayed (%/day)	Unsprayed to sprayed (%/day)
	0.000	0.1053E+04	0.4800E+04
	0.1667	0.4056E+04	0.1845E+04
	0.500	0.4425E+04	0.2016E+05
	1.175	0.2951E+04	0.1344E+05
	1.800	0.1053E+04	0.4800E+04

Sprayed zone leak rate:	Time (hr)	Bypass rate (%/day)	Annulus rate (%/day)
	0.0000	0.5000E-01	0.4500
	24.0000	0.2500E-01	0.2250

Unsprayed zone leak rate:	Time (hr)	Bypass rate (%/day)	Annulus rate (%/day)
	0.0000	0.5000E-01	0.4500
	24.0000	0.2500E-01	0.2250

Natural deposition
aerosol removal rate: 0.1500 hr^{-1}

Powers' spray removal:
Nozzle height: 85 ft
Mean cross section: 03230E+05 ft^2
Spray volume fraction: 1.0
Confidence level: 50%

Water Flow	Time	Flow rate/coverage area (flux)
	0.0	0.3937E-01 cfm/ft^2
	3.0	0.0 cfm//ft^2

Spray removal coefficients:	Time (hr)	Removal coefficient for elementals (hr^{-1})
	0.0000	1.5
	0.50	12
	1.8	5
	2.0	2
	8.0	0.4

	Time (hr)	Removal coefficients for organics
	0.0000	0.00

Annulus exhaust:	Time (hr)	Filter #1 flow rate
	0.0000	0 cfm
	0.0278	14000 cfm
	0.2778	1000 cfm

Filter #1 efficiencies:	Elemental iodine	0.0000%
	Organic iodine	0.0000%
	Aerosols	99.0000%

Filter #3 flow rate: 2000 cfm

Filter #3 efficiencies:	Elemental iodine	95.0000%
	Organic iodine	95.0000%
	Aerosols	99.0000%

Filter #4 flow rate: 0.1888E+01 m^3/s

Filter #4 efficiencies:	Elemental Iodine	95.0000%
	Organic Iodine	95.0000%
	Aerosols	99.0000%

CR exhaust: 2010 cfm

CR unfiltered inflow: 10 cfm

Dose Parameters

EAB X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1000E-02
2.0000	0.0000E+00

LPZ X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.1350E-03
8.0000	0.1000E-03
24.0000	0.5400E-04
96.0000	0.2200E-04

Filter #3 X/Q values:

Time (hr)	X/Q (s/m^3)
0.0000	0.2200E-02
2.0000	0.1500E-02
8.0000	0.1300E-02
24.0000	0.8400E-03
96.0000	0.4800E-03

Success Criteria

The deposition rate should be found to be reasonable.

Acceptance Criteria

All of the success criteria must be met or exceeded in order for the RADTRAD software to be acceptable to the NRC.

Results

		RADTRAD Case 24	RADTRAD Case 24A
EAB	Thyroid (rem)	68.6	68.6
	TEDE (rem)	4.54	4.54
LPZ	Thyroid (rem)	60.4	60.4
	TEDE (rem)	106	106
CR	Thyroid (rem)	14.3	14.3
	TEDE (rem	36.2	36.2

In the Powers spray model, the decontamination factors were derived in terms of mass fractions. The addition of aerosol to the mix will have no effect on dose due to this first minor assumption.

3.4 Configuration Control

One purpose of configuration control is to maintain a standard, recognized version of the code. Code assessment efforts are hindered when a code is undergoing continuous development. The code must be frozen, documented, and distributed to code users so that all users have the same code, and assessment results and user experience can be exchanged knowing that results are interrelated and are not specific to a unique version of the code. Freezing of the code is defined as the avoidance of changes in models and correlations to improve the code's predictive capability. Changes to the frozen code are allowed to correct errors, for improved input/output, and for user conveniences. The intent is to freeze the code for a sufficient time to establish a considered view of its capabilities and accuracy.

If an error is discovered by a user, the information (see Section 1.7) should be sent (via fax or e-mail) to the developers. The problem should be described and suggestions for possible fixes included. The problem will be reviewed to ensure that it is indeed an error and that the problem is relevant to conditions that might be expected to occur in a nuclear power plant. Error corrections will typically be released semiannually.

The use of the code assessment and applications is expected to reveal deficiencies that need to be addressed through code development. The information gathered during the period when the code is kept frozen will be considered continuously in preparing new versions of the code. A priority based implementation system will be used for all code revisions. User requirements to resolve safety and regulatory needs are the foremost determinant of priority.

3.5 References

[Bi95] N.E. Bixler, "Simple Model of Pipe Decontamination for RADTRAD," Internal Sandia National Laboratories Memorandum to D. Monroe, August 29, 1995.

[Br91] J.E. Brockmann, "Sampling and Transport of Aerosols," in *Aerosol Measurement: Principles, Techniques, and Applications,"* K. Wilke and P.A. Baron, Eds., Van Nostrand Reinhold, New York, 1991.

[Cl91] J.E. Cline, "MSIV Leakage Iodine Transport Analysis," NRC-03-87-029, Nuclear Regulatory Commission, Washington, DC, 1991.

[Di62] J.J. DiNunno, R.E. Baker, F.D. Anderson, and R.L. Waterfield, "Calculation of Distance Factors for Power and Test Reactor Sites," TID-14844, U.S. Atomic Energy Agency, Washington, DC, 1962.

[Fa84] Fauske and Associates, Inc., *FAI Aerosol Correlation*, An Industry Degraded Core Rulemaking (IDCOR) Program Report, Bethesda, MD, 1984.

Federal Guidance Report No. 11, "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion," USEPA, EPA 520/1-88-020 U.S. Environmental Protection Agency, Washington, DC, 1988.

Federal Guidance Report No. 12, "External Exposure to Radionuclides in Air, Water and Soil," EPA 420-r-93-081 U.S. Environmental Protection Agency, 1993.

[Mu74] K.G. Murphy and K.M. Campe, "Nuclear Power Plant Control Room Ventilation System Design for Meeting General Design Criterion 19," in *Proceedings of the 13th AEC Air Cleaning Conference*, CONF-740807, U.S. Atomic Energy Commission, Washington, DC.

[Po92] D.A. Powers and J.L. Sprung, *A Simplified Model of Aerosol Scrubbing by a Water Pool Overlying Core Debris Interacting with Concrete*, NUREG/CR-5901, SAND92-1422, Sandia National Laboratories, Albuquerque, NM, 1992.

[Po93] D.A. Powers and S.B. Burson, *A Simplified Model of Aerosol Removal by Containment Sprays*, NUREG/CR-5966, SAND92-2689, Sandia National Laboratories, Albuquerque, NM, 1993.

[Po95] D.A. Powers, K.E. Washington, S.B. Burson, and J.L. Sprung, "A Simplified Model of Aerosol Removal by Natural Process in Reactor Containments," NUREG-6189, SAND94-0407, Sandia National Laboratories, Albuquerque, NM, 1995.

[So95] L. Soffer, S.B. Burson, C.M. Ferrell, R.Y. Lee, and J.N. Ridgely, "Accident Source Terms for Light-Water Nuclear Power Plants," NUREG-1465, Nuclear Regulatory Commission, Washington, DC, 1995.

[St 95] S.A. Stage, "Computer Codes for Evaluation of Control Room Habitability (HABIT)," Draft, NUREG/CR-6210 (PNL-10496), Pacific Northwest National Laboratory, Richland, WA, 1995.

USNRC [74] "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Boiling Water Reactors," Regulatory Guide 1.3, Revision 2, U.S. Nuclear Regulatory Commission, Washington, DC, June 1974.

USNRC [74] "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Pressurized Water Reactors," Regulatory Guide 1.4, Revision 2, U.S. Nuclear Regulatory Commission, Washington, DC, June 1974.
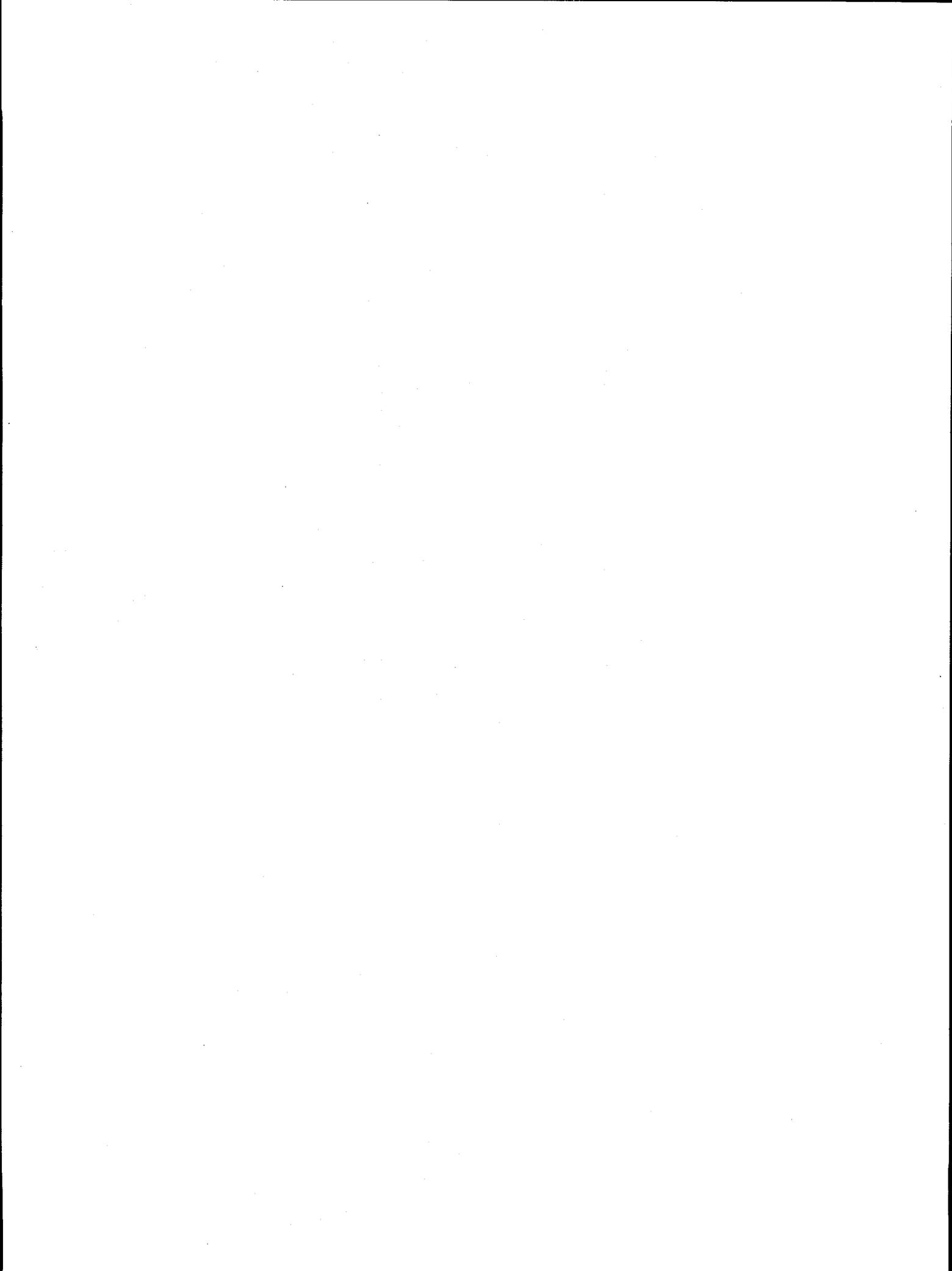
4 RADTRAD Programmer's Guide

The first two parts of this document have dealt with the RADTRAD from the user's perspective. They have provided the information needed to install and run the RADTRAD program and to understand and apply the results for the program. The last two parts deal specifically with the RADTRAD computer code. This material is intended for individuals who may be called upon to revise the code or place the code in a different shell. Chapter 3 deals with quality assurance (i.e., does the code solve the problem correctly?), while this section details the actual code and its logic.

4.1 General Computational Approach

RADTRAD is implemented as a modular code. It includes two distinct components. The first is written using Fortran and the Hi-Screen Pro II user-interface tool. It provides the graphical user interface (GUI) used for data input and permits RADTRAD to run one scenario after another without the user having to restart the program. Its first call is the INTROMENU, from which the user decides by the choice of screen where to go.

The other component is written in Fortran. It performs RADTRAD's computational tasks. This part of the document deals primarily with the second component. The computational part of the RADTRAD code consists of a main program (RADCALC) to control the program execution and 70 subroutines and functions to handle the data and perform the model calculations. Each program unit is coded using a structured approach.

4.1.1 Code Languages

The computational portion of RADTRAD is written using a subset of the ANSI Fortran-90 programming language.

4.1.2 Coding Standards

The following coding standards are followed in all RADTRAD Fortran program units.

The code for each program unit includes two blocks:

- definition block - the definition block includes the program unit name, history, description, and relationship to other units and INCLUDE files. It may also contain references, algorithm descriptions, and variable definitions.

- code block - code and comments.

The code block in each Fortran program unit begins with the type, and the dimensions of all variables are defined in type statements.

The primary method of passing variables between major program units is named "common blocks." Common blocks contain related information, and the block name indicates the general nature of the information. The common blocks are defined in code segments contained in INCLUDE files. The INCLUDE files also contain parameter statements, type definitions, and dimensions associated with the variables defined in the file.

Argument lists are used to pass variables to subroutines and functions if use of a formal argument list facilitates program development, verification, and maintenance. Variables are passed to functions via argument lists.

Structured programming techniques (IF ... THEN, ELSE IF... THEN, DO WHILE) have been used, and the unnecessary use of statement numbers has been avoided. END DO statements have been used to decrease the number of statement numbers.

The RADTRAD code aborts execution if an abnormal condition is encountered during execution of the code. Traps have been provided for abnormal conditions related to file operations, data input, and data output. In general, the error messages are written to the console, to the log file, and to other output files to describe the abnormal condition that is causing the code execution to be aborted.

The use of system-dependent calls has been limited to two places: (1) the numerical solution section where a call to ZPORC is used to return the zeros of a polynomial; and (2) the system subroutines, where there is a call to get the date and time of program execution from the system clock.

4.1.3 Data Input

RADTRAD is usually run through the interactive screen mode, but it may also be run in a batch mode. User interactions and data input are via data input files. The names of the run specification files (plant model file and scenario description file) are entered as command line arguments at the time code execution is initiated. The output file name is the third command line argument (XXX.OUT).

4.1.4 Interactive Input

When RADTRAD is run interactively via the GUI, then the user has the option of either entering the plant model and scenario description via the GUI, or specifying the file names of the data input files.

4.2 RADTRAD Code structure

4.2.1 RADTRAD Logic Flow

The RADionuclide Transport, Removal, and Dose code (RADTRAD) calculates doses to receptors, with the locations defined by the user. Locations may be at offsite locations, for

example, the exclusion area boundary or the low population zone, and in the control room. A general logic flow chart, with subroutine names given in parentheses, is given below. A detailed flow charge indicating all subprogram relationships is shown in Section 4.2.1.1.

Screen input (INTRO.IMG)

Initialization for RADTRAD [INITALL]

For each time interval [AUTODT]

> RADTRAD assumes a single-source compartment. Default source terms are for BWRs and PWRs, described in NUREG-1465 or in TID-14844 [SOURCE].

> Material is transported through the containment building, as well as through other buildings and the environment.

> Credit is taken for removal mechanisms. Containment sprays may remove aerosols, elemental iodine, and organic iodine. The flow between buildings or rooms may be through HEPA filters or a suppression pool. Leakage to the environment may occur [COEFFS].

> Evaluate matrix-inverse in Laplace space by transport group [INVMAT].

> Calculate separately the contribution factors from each compartment's nuclide inventory, source term, and the initial values and rates for the transport groups to each compartment's inventory at the end of the time step [COENUM, ZERODN, RESADER].

> Update the nuclide inventories in each compartment based upon transport results [XNUPDT].

> Calculate doses at the specified locations [DOSES].

> Calculate the decay and ingrowth of nuclides in the compartment atmosphere [DKNGRO].

> Edit results [PRINTOUT].

Prepare for another time step [AUTODT].

4.2.1.1 RADTRAD Flowchart

RADTRAD
    PARSEC1
    HSNEC
    RDSDF
    RDPMF
    RDRFT
    RDNIF
RADCALC

```
RDFLAG
INITALL
   PMFOUT
   RDNUCD
   NIFOUT
   RDINPD
   SDF
   SDFOUT
   RFTOUT
NECSTEPS
   SPINIT
   SORTER
AUTODT
SOURCE
   STERM
      OPOOL
      LUPC1
      XIVOLP
      XIVOLC
   COEFFS
   LUPP1
   RECIRC
   LUPC2
   XNTDEP
      LUPC2
      AEROSOL
      PWRSA
      PWRDBA
      BWRSA
      BWRDBA
      APWRDBA
   SPRY
      LUPC1
   PIPOUT
      LUPP2
   FOUT
      LUPP2
   SUPOUT
      LUPP2
   COUT
      LUPP2
PIPIN
      LUPP2
      BIXLER1
      BIXLER3
      BROCK
   FILTIN
      LUPP2
   SUPIN
LUPP2
   CIN
   INVMAT
   COENUM
   ZERODN
```

DZPORC
RADCALC (continued)

    NDPEXC
  RESADER
    EQUAL
     SUMPWR
  COENUM
  ZERODN
    DZPORC
     NDPEXC
  RESADER
    EQUAL
     SUMPWR
  COENUM
  ZERODN
    DZPORC
    NDPEXC
  RESADER
    EQUAL
     SUMPWR
  XNUPDT
  DOSES
  LUPL2
  DKNGRO
  PRINTOUT
  AUTODT
  ZRINV
  TSHIFT

4.2.1.2 Input Screen Subroutines

Screen names and numbers and the subroutines that create them are listed below. Note that only those screens that are currently active have subroutines. As additional models and options are included, additional screens will be written.

Screen Title	Screen Number	Subroutine Name
Welcome		
Main Menu	0000	INTROMENU
Plant Model	1000	MENU_PM
Load Plant Model	1100	FILE_PM
Nuclide Inventory	1200	INVEN_PM
Select Compartment	1300	COMPT_PM
Compartment Description	1310	CINFO_PM
Select Transfer Pathways	1400	TRANR_PM
Transfer Pathway Description	1410	PINFO_PM
Select Compartment	1411	SELECT_C
Review Plant Model	1500	VIEWFILE
Save Plant Model	1600	SAVE_PM

Screen Title	Screen Number	Subroutine Name
Filters		
User-Specified Filter Parameters	2420T	TPFIL_SD
Air Intake X/Qs	2420T2	LN_EV_SD
Suppression Pool	2430	TPSP_SD
User-Specified Decontamination Factors for Aerosol Removal	2431T	PAESP_SP
User-Specified Decontamination Factors for Elemental Iodine Removal	2432T	PEISP_SD
User-Specified Decontamination Factors for Organic Iodine Removal	2433T	POISP_SD
Air Leakage		
User-specified	2440t	PCONV_SD
Dose Calculation Input		
Select Dose Conversion Factors	2510	DOSECON
Create/Modify Dose Location Selection	2520	DOSE_SD
Dose Location	2520A	LNDOS_SD
Location Compartment	2521	SELEC2_C
Control Room	2522	LN_CR_SD
Environment	2523	LN_E_SD
Review Scenario Description	2600	VIEWFILE
Save Scenario Description	2700	SAVE_SD
Calculate Results	3000	SIMULATE
Examine Results	4000	RESULTS
Exit RADTRAD	5000	QUIT

4.2.2 Program Module Description

AEROSOL. This subroutine receives the decontamination coefficient as a function of reactor type (PWR or BWR) and release scenario (design basis accident or severe accident) in units of hr^{-1} and converts it to s^{-1}. The correlations used are discussed in Section 2.2.2.1.2. It is called by the routine controlling natural deposition, XNTDEP.

APWRDBA. This subroutine calculates the decontamination coefficient for natural deposition using the Powers model for a design basis accident in an AP-600 reactor. It is called by the main routine controlling aerosol deposition, AEROSOL.

AUTODT. This subroutine determines the next time step based on user-specified events and a manual time step control called by the drive routine, RADCALC.

BIXLER1. This subroutine calculates the decontamination coefficient for elemental iodine in a pipe as discussed in Section 2.2.6.2. It assumes that revaporization is negligible. It is called by the routine controlling pipe deposition, PIPINB.

BIXLER3. This subroutine calculates the decontamination coefficient for organic iodine in a pipe as discussed in Section 2.2.6.3. It assumes that revaporization is negligible. It is called by the routine controlling pipe deposition, PIPINB.

BROCK. This subroutine calculates the transport efficiency of aerosols for piping pathways as discussed in Section 2.2.6.1. The subroutine assumes continuous flow from the pipeway inlet. It is based upon a lumped-node model description. Subroutine BROCK includes the following effects: (1) gravitational settling, for low-flow-rate conditions; (2) turbulent inertial deposition, along straight pipe sections; (3) Brownian diffusion, along straight sections of pipe; and (4) inertial deposition in bends. It is called by the routine controlling pipe deposition, PIPINB.

BWRDBA. This subroutine calculates the decontamination coefficient for natural deposition using the Powers model for a design basis accident in a boiling water reactor. It is called by the main routine for aerosol deposition, AEROSOL.

BWRSA. This subroutine calculates the decontamination coefficient for natural deposition using the Powers model for a severe accident in a boiling water reactor. It is called by the main routine for aerosol deposition, AEROSOL.

CIN. This subroutine calculates the normalized flow into the compartment due to convection (air leakage). The user specifies the compartment volume and the volumetric flow rate between the compartments. These values are returned as removal coefficients (s^{-1}) for the transport groups (1) nobles, (2) elemental iodine, (3) organic iodine, and (4) aerosols. This routine is typically used in determining leak rates from containment. It is called by the coefficient driver routine, COEFFS.

COEFFS. This subroutine combines the coefficients for the individual removal and transport mechanisms to obtain the system matrix for the differential equation governing nuclide removal and transport.

For each of the four transport groups, there will be obtained a set of coefficients, C_{ij}, with the indices i and j designating compartment numbers. The value of C_{ij} is positive when it corresponds to a loss in the content of the ith compartment. It is negative when it corresponds to a gain in the content of the ith compartment. This loss or gain is proportional to the content of the jth compartment. At present, all losses occur on the diagonal of the system matrix and all gains occur off the diagonal. This is because there are no removal mechanisms that can affect removal in another compartment.

COENUM evaluates the numerator of the transformed equation in Laplace space. One such numerator exists for each compartment location. It is used in combination with ZERODN and RESADER to evaluate the transport of radionuclides. It is called by the main driver routine,

RADCALC, three times to calculate each compartment's nuclide contribution to every other compartment.

COUT calculates the flow out of a compartment by way of a pathway as a result of convection (also referred to as air leakage) for each transport group. It is called by the main driver routine, RADCALC, three times to calculate each compartment's nuclide contribution to every other compartment.

DKNGRO calculates the radioactive decay and daughter in-growth for all nuclides. It is called from the main driver routine, RADCALC.

DOSES. Environment and control room doses are calculated for receptors located at user-defined locations [e.g., exclusion area boundary (EAB), low population zone (LPZ), control room operator]. The user supplies the X/Qs and breathing rates as a function of time for each location. The user also supplies the occupancy factors as a function of time for the control room. It is called from the main driver routine, RADCALC.

DZPORC returns the double precision or the complex zeros of a given polynomial with double precision coefficients. The required inputs are NDEG, the degree of the polynomial, and COEFF, the vector of the double-precision coefficients (with the zeroth power occurring first). The output is ZERO, the vector of double precision or complex roots (whose number is NDEG).

EQUAL. This subroutine returns 1 if the two arguments are equal or nearly equal to each other and a 0 if they are not. The degree of equality is determined by the values of ABS_EPSILON and REL_EPSILON, which are defined in icode\constant.h. It is called from RESADER.

FILTIN. This subroutine calculates the flow rate and removal coefficient called from RESADER for filtering incoming air. The coefficient is calculated for each transport group for the given time step and is stored in the array FILFIN(4). The user must specify the volume of the "from" compartment, the flow through the filter, and the efficiency of the filter for the various groups. The routine is called by the coefficient evaluation routine, COEFFS, and is discussed in Section 2.2.7.

FOUT. This subroutine calculates the flow rate for filtered air. The user must specify the volume of the "from" compartment and the flow through the filter for the various groups. The routine is called by the coefficient evaluation routine, COEFFS.

INITALL sets input for the RADTRAD program reads. It calls routines that read the nuclide inventory and dose files discussed in Section 1.4.3.3 and that edit the plant model file information and the scenario description file. It is called up from the main drive routine RADCALC.

INTRO.IMG generates the "Welcome to RADTRAD" initial input screen, which then calls the main menu screen (screen number 0000), where the user begins the input process.

INVMAT. This subroutine determines the inverse of the Laplace system matrix (the resolvent matrix) using an algorithm called Leverrier's algorithm (also called Fadeeva's method). If A is

the system matrix, I is the identity matrix, and s is the Laplace transform variable, then the resolvent matrix can be defined as:

$$(sI-A)^{-1}$$

It is called from the main drive routine, RADCALC.

LUPC1 is a lookup table function for one-dimensional arrays; for example, the overlying pool tables.

LUPC2 is a lookup table function for two-dimensional arrays; for example, the filter and spray tables.

LUPL2 is a lookup table function for two-dimensional arrays; for example, the control room occupancy factor and breathing rates.

LUPP1 is a lookup table function for one-dimensional arrays; for example, the X/Q for the control room inlet.

LUPP2 is a lookup table function for one-dimensional, double-precision arrays; for example, the piping deposition tables.

NECSTEPS. This subroutine determines the minimum set of time steps that are necessary to capture all of the events and other system changes that are included in the user input. It is called from the main driver routine RADCALC.

NIFOUT outputs the nuclide inventory file data if the detailed output control variable (LEVEL-NIFOUT) is set greater than 1 in FLAG.SET.

OPOOL. For each of the four transport groups, this subroutine calculates decontamination factors resulting from an overlying pool. Both user-provided and model-developed decontamination factors are implemented in this subroutine. The model is discussed in Section 2.2.3. The effects considered in this subroutine only occur during the ex-vessel portion of the release.

PIPIN. This subroutine calculates the removal rate for material flowing into a compartment by way of a pipeway, as discussed in Section 2.2.6. The user may specify the flow rate for iodine and aerosol transport groups. In addition, the user may specify the DFs for these same transport groups or request that they be obtained using the Brockmann/Bixler algorithms. They are called from the coefficient evaluation routine, COEFFS.

PIPOUT. This subroutine calculates the normalized flow out of a given compartment by way of piping for all four transport groups. It is called from the coefficient evaluation routine, COEFFS.

PMFOUT. This subroutine outputs plant model file information if the detailed output control variable (LEVEL_PMFOUT) is set greater than 0 in FLAG.SET.

PRINTOUT. This routine handles all user-requested RADTRAD output. All other output from all other routines should be used for debugging purposes only. This debug output will be interspersed among the normal descriptive and dose output, but should be completely turned off for most runs. Compartment detailed output is stored and printed after the dose output. The detailed output contains information about nuclide and transport group inventories for each compartment for which detailed output is requested.

The descriptive information describes the software, model, and scenario used to obtain the resulting output.

The dose information is the organ, whole-body, and TEDE doses in sieverts at the end of each user-defined time step. Both accumulated doses and those acquired during the time step are given.

If requested, nuclide inventories are given in atoms, kilograms, curies, and becquerels at the end of each user time step. Transport group inventories are given in atoms and kilograms.

PWRDBA. This subroutine calculates the decontamination coefficient for natural deposition using the Powers model for a design basis accident in a pressurized water reactor. It is called by the aerosol deposition main routine, AEROSOL.

PWRSA. This subroutine calculates the decontamination coefficient for natural deposition using the Powers model for a severe accident in a pressurized water reactor. It is called by the main aerosol deposition routine, AEROSOL.

RADCALC. This is the main driver routine for the calculational aspects of RADTRAD. It calculates doses to receptors having locations defined by the user. Locations may be at the site boundary, in the low population zone, and in the control room.

RDFLAG reads detailed-output control flags from FLAG.SET for subroutines.

RDINPD reads dose information from MCODE\DOSEDATA.INP. It is called from the input control routine, INITALL.

RDNUCD reads nuclides, atomic weights, half-lives, and half-life units of measurement information from MCODE\NUC.NIS. It is called from the input control routine, INITALL.

RECIRC. This subroutine calculates the removal coefficient for the recirculating filters in a compartment. The subroutine loops over all transport groups. The user provides the filter efficiency as a function of transport group, flow rates, and volume information. The routine is called from COEFFS and is discussed in Section 2.2.7.

RESADER. This subroutine calculates the amount of each transport group in each compartment using the method of residues, which is the process of inverting the Laplace transform obtained in solving the first-order differential equations describing transport and removal within the system. A sequence of eleven code blocks (designated as RESADER0, RESADER1,...,RESADERX) is utilized to process the denominator roots of the transform. The first block of code, RESADER0,

is used to determine the level of multiplicity, or repetitions, in the denominator. The other blocks of code are used for each level of multiplicity; thus a multiplicity level of 3 would use the RESADER3 block of code. When there is more than one zero in the denominator, an analytical solution of the derivative is determined in this routine. The technique is discussed in Section 2.4.2.

RFTOUT. This is a subroutine to produce output concerning the release fractions and timings when the detailed output control variable (LEVEL_RFTOUT) is set greater than 1 in FLAG.SET.

SDF. This is a subroutine that can be used to override scenario input.

SDFOUT. This is a subroutine to output a data set in 'SDF.FOR' concerning the scenario descriptions when the detailed output control variable (LEVEL_SDFOUT) is set greater than 1 in FLAG.SET.

SORTER. This subroutine does a selection sort on the NVAL elements of the double-precision array VALS. It returns the sorted elements in the same array. These elements are time values in RADTRAD, but any set of double-precision numbers can be sorted in the same way.

SOURCE. This subroutine controls the calculation of source material in each compartment. Source material arises from core heatup and degradation determined by the user's choice of inventory and release fractions. It is called from the main driver RADCALC and is discussed in Section 1.4.3.

SPINIT is the Powers spray model initialization routine. It is used to estimate the internal time steps need for stability of the model due to the intense removal of aerosols.

SPRY. This subroutine determines the removal coefficients for all four transport groups due to the action of sprays. It is assumed that no removal effect occurs for noble gases. For the other three transport groups, the removal coefficient can be specified by the user. For the aerosol transport group, the removal coefficient can also be calculated using the Powers mechanistic model. This is discussed in Section 2.2.1.

STERM. This subroutine calculates the release rate of material from the core inventory to the source term compartment. It also accounts for the effects of decay.

SUMPWR is the sum of the inverse numerator powers, less the sum of the inverse denominator powers. Each numerator power is of the form $(s-zn)^{**}(-n)$, where s is equal to the given denominator zero for which the residues are being determined. If s happens to equal zn, then the term is excluded from the sum. In this case a numerator multiplicity is said to occur, and the SUMPWR will apply to the reduced function. Each denominator power is of the form $(s-zd)^{**}(-n)$ and is multiplied by its denominator multiplicity. When s happens to equal zd, then the term is excluded.

SUPIN. This subroutine calculates the removal coefficient for material flowing into a compartment through a suppression pool. The user must specify DFs for elemental iodine, organic iodine, and aerosols. This is discussed in Section 2.2.5.

SUPOUT. This subroutine calculates the normalized flow out of a given compartment by way of a suppression pool. The values obtained are returned in the array SUPFL(4).

TSHIFT shifts results and updates old values to new values at the end of a time step.

XNTDEP. This subroutine calculates the removal coefficient for natural deposition. This removal mechanism includes many phenomena, such as gravitational settling, impaction, and diffusion. The subroutine considers all four transport groups. However, natural deposition is considered applicable only to elemental iodine and aerosols. Noble gases and organic iodine are not affected because they are nonreactive.

The removal coefficients for elemental iodine and aerosols can be specified by the user. In the case of elemental iodine removal, the user should include the effects of reemission of iodine, because this effect is not modeled explicitly. The removal coefficients can also be determined from either Henry's correlation or the Powers model as discussed in Section 2.2.2.

XNUPDT updates the nuclide inventory. It updates inventories using previous compartment inventories and the inventory and source term contribution factors. It only deals with nuclides transported in the atmosphere. Nuclides in other compartment sublocations are not transported. The only source term rate per nuclide is the primary source term from the source term compartment.

ZERODN for each transport group, subroutine ZERODN, determines the zeros of the scalar denominator and the zeros of the vector numerator.

ZRINV is the routine used to zero the inventories in a particular type of compartment. This routine was written for general use, but currently is used only for environment compartments (compartment type = 3). The current use is to zero environment inventories for plume simulations.

4.2.3 Diagnostic Control

To obtain additional output for a particular subroutine, a level-of-detail system is used. In this system, increasing the flag value from 0 to 5 will increase the information flow. It is recommended that the user start with values like 1 or 2 and trace through the logic to localize the problem. Below is the standard level of detail flags that exist in file FLAG.DAT.

```
FLAG.DAT ( FLAGS FOR LEVEL-OF-DETAIL IN DIAGNOSTIC OUTPUT )
0    LEVEL_AQUEOUS
0    LEVEL_CIN
0    LEVEL_COEFFS
0    LEVEL_COENUM
0    LEVEL_COUT
0    LEVEL_DECAY
0    LEVEL_DOSES
0    LEVEL_ENERGYC
0    LEVEL_ENERGYP
0    LEVEL_EQUAL
```

```
0    LEVEL_EXTEDE
0    LEVEL_FILTIN
0    LEVEL_FOUT
0    LEVEL_INITALL
0    LEVEL_INVMAT
0    LEVEL_LUPC1
0    LEVEL_LUPC2
0    LEVEL_LUPC3
0    LEVEL_LUPL2
0    LEVEL_LUPP1
0    LEVEL_LUPP2
0    LEVEL_MASSTR
0    LEVEL_NECSTEPS
0    LEVEL_NIFOUT
0    LEVEL_NUCLIDE
0    LEVEL_OPFLAG
0    LEVEL_OPOOL
0    LEVEL_OUTPUT
0    LEVEL_PIPIN
0    LEVEL_PIPOUT
0    LEVEL_PMF
0    LEVEL_PMFOUT
0    LEVEL_PRINTOUT
0    LEVEL_RADCALC
0    LEVEL_RDBWR
0    LEVEL_RDFLAG
0    LEVEL_RDINPD
0    LEVEL_RD_NIF
0    LEVEL_RDNUCD
0    LEVEL_RDPMF
0    LEVEL_RDPWR
0    LEVEL_RECIRC
0    LEVEL_RESIDUE
0    LEVEL_RFTBWR
0    LEVEL_RFTOUT
0    LEVEL_RFTPWR
0    LEVEL_SDF
0    LEVEL_SDFOUT
0    LEVEL_SORTER
0    LEVEL_SOURCE
0    LEVEL_SPRY
0    LEVEL_STERM
0    LEVEL_SUPIN
0    LEVEL_SUPOUT
0    LEVEL_TSHIFT
0    LEVEL_XIVOLC
0    LEVEL_XIVOLP
0    LEVEL_XNTDEP
0    LEVEL_XNUPDT
0    LEVEL_ZERODN
0    LEVEL_ZRINV
```

4.3 RADTRAD Executable and Source Code Listing

The RADTRAD executable and source code listing is available in electronic format on 3.5-inch high-density IBM PC-compatible floppy disks. Either is available by request from:

Sandia National Laboratories
Accident and Consequence Analysis Department
P.O. Box 5800
Albuquerque, NM 87185-0748

(505) 844-3321 (fax)

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10. SUPPLEMENTARY NOTES

Jay Y. Lee, NRC Project Manager

11. ABSTRACT *(200 words or less)*

This report documents the RADTRAD computer code developed for the U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation to estimate transport and removal of radionuclides and dose at selected receptors. The document includes a users' guide to the code, a description of the technical basis for the code, the quality assurance and code acceptance testing documentation, and a programmers' guide. The RADTRAD code can be used to estimate the containment release using either the TID-14844 or NUREG-1465 source terms, and assumptions, or a user-specified table. In addition, the code can account for the reduction in the quantity of radioactive material due to containment sprays, natural deposition, filters, and other natural and engineered safety features. The RADTRAD code uses a combination of tables and/or numerical models of source term reduction phenomena to determine the time dependent dose at user specified locations for a given accident scenario. The code also provides the inventory, decay chain, and dose conversion factors needed for the dose calculation. The RADTRAD code can be used for occupational radiation exposure assessments, typically in the control room, for site boundary dose estimates, and for dose attenuation estimates due to facility or accident sequence modifications.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

nuclear power reactor accident, design basis accident, severe accident, source terms, removal mechanisms, environment dose, control room dose

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